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Autonomous Irrigation Robotics System
100% Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Armando Camacho, Frank Azcuy, and Benjamin Sturman and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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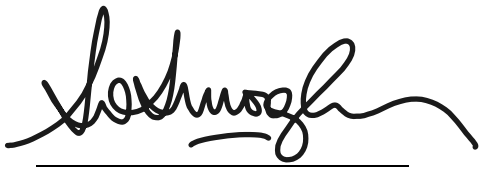

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Abstract

For this project, the goal is to design a system that is capable of autonomously administering water and plant nutrients over a grassy terrain within the boundaries specified by an end user. This will be accomplished by designing a weather proof chassis that houses onboard electronics that will be responsible for the autonomous behavior desired.

The water delivery system will be a lightweight hose that is resistant to kinking, catching on obstacles, or becoming entangled. In order to further mitigate this issue, the hose attachment on the robot will be able to rotate in any direction so that the hose is always facing towards the main water source.

The power source will be an onboard battery that will be charged by a charging station that will be installed where the end user desires. This charging station will also double as the "home" port for the robot itself.

1. Introduction

1.1 Problem Statement

In the past decade, the field of robotics has grown considerably in a short amount of time. There are countless innovations in robotics applications that are available to consumers because robots have become relatively cheap to buy and/or build. For example, Unmanned Aerial Vehicles (UAVs) and manufacturing processes have benefitted from this booming industry. The possibilities for the applications of robots and autonomous systems are only restrained by the designer's creativity.

Unfortunately, in the field of agriculture, specifically in residential lawn care, little advancements have been made that take advantage of the benefits that the field of robotics can offer. There is a lack of products and systems at the residential level that can water lawns and this is due to the fact that very few companies are conducting product development in this specific area.

Caring for and maintaining a yard requires time and resources to insure that it is healthy and aesthetically pleasing to the eye. Designing an autonomous robot that can water a given area such as a residential lawn can make maintenance of the area far more efficient and cost effective.

1.2 Motivation

One main components of lawn care is watering the lawn itself and its surrounding plants. This action alone is simple, yet time consuming enough to create a system to do it autonomously and more importantly, in an efficient fashion. A robot that is capable of watering a lawn autonomously is a very convenient and cost-effective product. Due to the cost of sprinkler installations and ongoing maintenance costs, conventional sprinkler systems can be expensive [1]. Additionally, dry areas that cannot be reached by use of these conventional sprinkler systems can now be watered by the mobility of the robot. The largest benefit for the environment is the conservation of a vital natural resource and that resource is water.

Figure 1: Conventional Sprinkler System [2]

1.3 Literature Survey

Currently, there are a few products on the market that are capable of being considered as moving sprinklers. Figure 2 shows a system called the Water Walker that uses the hydraulic pressure available through a traditional garden hose to move forward and water its surroundings [3].

Figure 2: Water Walker System [4]

The main issue with the Water Walker is its inability to move freely in any direction and must travel along a unidirectional predetermined path set by a hose in order to move. This track is required to be laid down and picked up every time it is used. If not, it will be unsightly and can possibly damage the grass over time. This track placement by the end user makes this product non-autonomous as well as tedious. It also moves at a very slow place making the possibility of over watering, which can cause damage to the lawn an issue.

A currently available product for autonomous plant watering is the Droplet Robotics Sprinkler [5]. It is capable of connecting to databases in order to check weather patterns [5]. This allows it to calculate how much watering is needed or if watering is required at all. Figure 3 shows a product illustration.

Figure 3: Droplet Robotics Sprinkler [5]

This system is autonomous and requires little to no human input, but is unable to move about freely and only has an effective range of 30 feet [5]. Therefore, several units would be required to achieve complete coverage for a medium sized yard. These units are expensive and require a conveyor such as a hose in order to transport water to the unit. These hoses may not be ideal for an end user concerned with aesthetics and cost. If a new area is to be watered by this system, relocation would be required for both the robot and the water connection which may be time consuming and cumbersome.

In the market, there exists several autonomous vacuum cleaners whose operating functions are very similar to what this project intends to achieve, covering a large space autonomously with object avoidance. However in this case, instead of cleaning a floor, an area will be watered. These autonomous vacuums are appropriately sized, battery powered, and can clean an entire floor of a house effectively [6].

Figure 4: An Autonomous Robotic Vacuum Cleaner [6]

Figure 4 shows one such example of an autonomous robotic vacuum cleaner. These robots functionality, usefulness, and overall market share prove that a sprinkler robot is definitely a feasible product. The advantage of choosing a sprinkler design that is autonomous and mobile is that it has a much larger effective range while requiring no human input. Once the system is finished with its watering routine, it can return to its charging station, and prepare for the next watering cycle as set by the end user. The modifications required for a robot with a sprinkler design would be to design it with the harsh elements that come from an external environment such as rain, snow, heat, and dust while making sure that it is capable of traversing tough terrain.

1.4 Survey of Related Standards

The design of any system must adhere to constraints and standards set by a regulating body that specializes in the design of said system. The Occupational Safety and Health Administration (OSHA) Standard Number 1910.211 and ISO 13482:2014 has requirements and procedures in place for the safe operation of robots by end users [7] [8]. In the case of the autonomous sprinkler system being designed, it must be safe to approach if the user wants to modify or relocate the system manually while the system is in operation. Integrating a sensor into the sprinkler system that turns off the sprinkler assembly when animals or humans approach would be a requirement set forth by this standard.

For irrigation systems, the Irrigation Association (IA) & American Society of Irrigation Consultants (ASIC) state that an irrigation system shall be designed so as to distribute water at a safe and efficient flow rate while adhering to local regulations on water use and consumption [9]. Some additional considerations are to include a mechanism that can record the amount of water used for future management of water consumption data, prevent runoff water or unnecessary watering of areas [9]. Other consideration would be to protect the system from harsh weather conditions such as freezing temperatures as well as measures to prevent vandalism of the system. A full outline of these standards can be found on the IA website.

The Institute of Electrical and Electronics Engineers (IEEE) places standards on the safety of electronic systems. IEEE 802.11 states that wireless transmissions of devices shall not interfere with nearby systems where the interference may create a safety hazard [10]. In the event of electrical failure, a failsafe should be implemented to prevent any large scale damage to the surrounding area or persons [10].

2. Project Formulation

2.1 Overview

In this chapter, project objectives will be discussed as well as an introduction to the design that is being considered. Along with this discussion, design specifications will also be presented and the reasons why they are required in order to create an effective system that is capable of meeting project objectives. In addition, a major subject of this project is global design and how it will be addressed to ensure that the design is globally conscious and friendly. Finally, constraints and other considerations will be brought forth at the end of the chapter and the steps taken to account for these constraints.

2.2 Project Objectives

The main goal for this project is to design a new irrigation system. The Autonomous Irrigation Robotics System (ARSS) which will be for use in residential lawn care applications. More specifically, an autonomous robot that requires minimal human interaction in order to function similarly to a conventional sprinkler system. An onboard computer can perform the necessary calculations and actions required in order to maneuver the system once first time set up is completed.

Additionally, this system needs to be just as, if not more, efficient as a conventional sprinkler system and remain environmentally friendly. Taking these objectives into consideration, an autonomous sprinkler system can be a suitable replacement to any sprinkler system currently in use today.

Keeping the cost low is an important objective in order to facilitate widespread adoption for the majority of current consumers. Furthermore, it should be a viable replacement for current systems that require lengthy construction, high initial costs, costly maintenance, or a possible choice for first time owners interested in lawn care.

2.3 Design Specifications

ARSS will have several features that will provide a realistic alternative to several different lawn watering systems offered to consumers. A reasonable alternative requires a cost benefit over other systems. So an important design specification is the requirement of a low cost system that is relatively inexpensive to manufacture.

As a residential lawn care product, the ARSS system should be lightweight and easy to move in the event of relocation of the system. Ease of use is another main design specification. Therefore, a friendly user interface that the end user will interact with to instruct the ARSS as well as simple first time set up will be a design goal. Moreover, a valve which affects the effective radius of the robot can be used for smaller sized lawns.

There are several methods to providing power to a system, but in the case where the ARSS will be located outside most of the time; solar energy is a reliable and sustainable energy source. Keeping global awareness and environmental consequences in mind, solar energy is the most natural but most involved decision for powering ARSS. Hydraulic pressure is another possibility where the pressure from the residential water source can be used to power certain components of the robot.

Perhaps the most important design feature is the requirement of ARSS being able to withstand several harsh weather conditions such as rain, snow, hot, and humid weather or combinations of these conditions. Failure to account for these factors may lead to premature failure of the system by overheating or water damage.

The integration of sensors into ARSS such as proximity sensors, humidity sensors, and temperature sensors among several will create a smart robot that can make decisions on how much to water or if watering the area is required at all.

2.4 Addressing Global Design

In a fast paced world where standards are commonplace, there needs to be an order of consistency between different standards that account for the same phenomena. One dominant example for this that still creates problems today is the use of both the SI as well as the Imperial system of measurements. The United States continues to use the Imperial system in an economy where the SI system is the dominant standard for measurements among most countries. One global learning component that can be used in this project would be the use of both measurement systems to expand the reach of this project to other parts of the world outside of the United States.

Machines today are more complex than they have been in past centuries. With added complexity to these systems, their inherent danger is much more real and apparent. If a project or product is to be used around the world, one of the biggest obstacles would be the language barrier among countries. There are hundreds of languages in the world with only a few major ones so the most realistic goal would be to create manuals in 3 or more languages and use industry standard danger symbols to alert any users of serious injury no matter what language they may speak.

Creating a safe operating environment for any system is crucial to widespread adoption in a global sense. Taking into account different backgrounds and making sure the users are safe no matter the language barrier is a first step in global design.

A major problem today that is a controversial topic is climate change caused by industrial processes and secondary sources of pollution. Around the world, manufacturing processes release millions of tons of greenhouse gases every year. Recent movements and laws have caused companies to rethink manufacturing designs to be more environmentally friendly.

In most countries, there is an official currency that is used for the purchase of goods and services within its borders. Due to economic conditions within the country and other external factors such as location and resources, the relative value of any currency can be worth more or less when compared to other currencies. One example is the Euro and the Dollar and how their different values can cause problems when products are sold overseas.

Conducting a cost analysis in different currencies and locations can help demonstrate how it may be preferable to conduct business/manufacturing in another country because of the price of resources and labor. At the same time, differing prices can be set to stifle income inequality in several countries. A product that can be sold at a high profit margin in the United States can be sold at a much lower price in developing countries while still profiting from sales.

Due to the lack of standardization across several countries in power grid design and outlet designs found in homes, there exists a variety of connections and adapters in order to accommodate several products created in different parts of the world. One issue that always occurs in the design of electrical components is how a 110/220V or 50/60Hz system will be integrated into an existing or changing design. Changing the design to allow for this is an important aspect of creating a product or system that can be used anywhere in the world regardless of electrical standards.

2.5 Constraints and Other Considerations

As with every project, constraints are unavoidable and must be accounted for. The ARSS system must carry its weight as well as the weight and friction that come as a result of carrying a hose along with it. The system should not weigh so much as to prevent movement of the robot as it carries it out its task. The robot should be manufactured with weight in mind.

As the ARSS moves around the boundary to be watered, the location and position of the hose must be kept in mind because possible blockages or tangling may occur which will prevent normal operation. A light weight hose must also be paired with a programmed behavior where the robot will always have its fluid inlet pointing in the direction of the water source. This will reduce the possibility of tangling and aid the robot to maneuver more effectively.

Outside the realm of design, local watering regulations must be obeyed and is at the sole discretion of the end user. Moreover, to prevent mishaps of water wastage, should the system be unable to move about because of blockages or obstructions, a check will be made by onboard instruments every minute to make sure that in the event that a blockage does occur, the water source will be turned off.

Yards come in several shapes and sizes and in the event that a yard is too small, the flow rate can be modified using the system interface to decrease the watering radius of the sprinkler. Furthermore, yard owners may have more than one area to be watered so different profiles may be set on the robot where the appropriate profile can be selected for the corresponding area to be watered.

3. Design Alternatives

3.1 Overview

As previously mentioned due to the various obstacles that the ARSS may encounter in one's yard, and the fact that it will be outdoor constantly, there will many critical parameters that need to be considered in all design alternatives. First is the use of a sensor and control system in order for the robot to determine the area that the user defined as needing to be watered. Second, because the robot will be primarily outdoors, it will need the necessary motors and proper wheels to travel over any obstacles found in a typical household. The robot will also need to be designed to be weather resistant due to the many elements it may encounter outside. Finally, one of the robot's most crucial parameters, the hose system, must be designed so that it will be able to water an area as efficiently as possible without getting tangled with itself or anything else it may encounter. These critical parameters will be incorporated in all the design alternatives as well as other parameters that will be discussed in further detail in the next sections.

3.2 Design Alternate 1

The primary focus for each design alternative is the orientation of the hose nozzle with respect to the main water source. It is for this reason that this design allows the robot to strafe from left to right, ensuring that the nozzle is always pointed in one direction. This is achieved by using four Mecanum wheels with their own separate electric motors. With four motors, this will help the robot gain traction. An added advantage to having the robot move in this motion is to allow more freedom in avoiding objects effectively [11].

Figure 5: Four Wheel Mecanum Drive Robot [11]

The disadvantage with type of drive system is that these wheels cannot be used on various surfaces. This is due to the lack of grip these wheels can provide. Another issue with this drive system is that it will not be able to climb over obstacles. Finally, because this is a specialty drivetrain, it is very expensive which might deter consumers from buying this product [11].

3.3 Design Alternate 2

The second design alternative has a three Omni wheel drivetrain. Similar to the first design alternative, this drive system allows for the robot to travel in any direction. However because it has one less wheel, the orientation of each wheel is angled so that it still has the same maneuverability as a four wheel drivetrain.

Figure 6: Three Wheel Omni Robot

This design focuses on taking the positives from the previous design but at the same time cutting the overall cost. By removing one wheel and one motor, is it possible to significantly cut the material cost of the robot. Even though the second design alternative addresses some issues such as cost and maneuverability, the robot with the use of this drive system will not have the necessary traction to be used on grass.

3.4 Design Alternative 3

The final design alternative is a two wheel, circular robot similar to the Roomba shown below. Each wheel will be powered separately with their own individual electric motors. It will contain a rechargeable battery pack as well as various sensors to determine its location and return home to the docking station [12].

Figure 7: iRobot Create 2 Programmable Robot [12]

Where it varies is in the size of the wheels and motors in order to compensate for any tall grass or slopes that the robot may encounter outside. Also, since it will not have the same maneuverability as the previous design alternatives, the hose attachment on the robot will be designed to rotate as the robot changes direction. This will help ensure that the hose will not get tangled on the robot.

3.5 Integration of Global Design Elements

The integration of global design elements will begin with the first and foremost important aspect of the ARSS system. How will it charge and operate using various power grids. Within the ARSS there will be a space specifically designed to house a transformer so that it will be usable on all types of power grids. For example, countries that run on 220V with 50Hz will have the same base model ARSS sent to them as the ones in the United States. However, during manufacturing different transformers will be installed depending on their end destination. In order to adjust for the two most common power grid configurations there will be models that utilize 120V at 50/60Hz as well as 220V at 50/60Hz using these transformers.

Safety is a top priority for the ARSS as it will be marketed to the everyday consumer. Due to this fact, a large number of safety factors and precautions will be introduced into the ARSS system. First and foremost will be clearly visible warning labels on the ARSS itself. Cautionary warnings against electric shock, touching and/or transporting the ARSS while it is in operation, and other pertinent warning labels required by the aforementioned standards will be implemented. Other safety factors include onboard sensors to monitor the ARSS during operation. A pressure sensor to monitor the flow of water within the system will turn the system off if pressure becomes too high or low. Temperature sensors will be implemented within the system as well so as to prevent a meltdown or possible explosion due to fluid leakage.

Higher levels of detailed warnings for operation will be included within the manual of the ARSS system. This operation/safety manual will be available in the language of whatever country that the ARSS is sold in. These manuals will include detailed instructions on the set up, usage, maintenance, safety precautions, and storage of the ARSS system.

The calculations and final specifications of the ARSS system will be done and presented using the SI unit system. However, similar to the language translations available, US units will be converted and available on the United States models.

3.6 Feasibility Assessment

The feasibility of any new product design must be weighed using its pros and cons, the innovations as well as the roadblocks. These pros and cons are based mostly off of the advances in robotics that have been made recently as well as technology that has been available.

One of the aspects of current autonomous technology that is a benefit to the ARSS is the tracking system shown in the Roomba Create 2. This type of system utilizes onboard sensors and memory to avoid obstacles while also recalling and tracing the predetermined paths needed to clean the room [12]. This is a feature that is applicable to the ARSS as it solves many of the problems mentioned previously. A few of them being object and obstacle avoidance, proximity sensors for pets and humans, and proper mapping when traveling to locations that need watering. Finally, the software will be designed for a simple one time user input during the initial set up of the ARSS.

Current battery advances have allowed for components to be small enough to fit onto the ARSS without causing a hindrance to the overall weight or maneuverability of the system. The docking station to be used as the home “base” for the ARSS has also been tested and proven to be an effective and feasible method for the updating and charging of an autonomous robotic system.

Similarly, servos and motors have become smaller, more powerful, and their efficiency has improved. This will allow the ARSS to employ small servomotors in order to power each of its wheels. These motors will allow the ARSS to traverse rougher terrains, higher grass, and even small obstacles such as sticks or rocks in order to reach its destination.

The rotational base for the sprinkler apparatus on top of the ARSS allows it to turn in any direction while simultaneously keeping its supply hose pointed in the direction of the water source. This will diminish the torque that would have been applied to the ARSS which can cause wear and tear on the sprinkler apparatus as well as pulling the ARSS off course.

IR technology allows for a very precise and strong communication network for the directional/location system of the ARSS. IR can be used to update the onboard systems in order to eliminate the need for another plug and or connection on the home dock. This will ensure that ease of docking is maintained while also extending the longevity of the system.

The feasibility of the ARSS is high due to the recent advancements in robotics as well as the already proven and available autonomous robots on the market today. Examples of these autonomous robots are the Roomba Create 2, the Water Walker System, and the Droplets Water Sprinkler. The goal with this design is to build upon the already established robotic principles demonstrated by already existing autonomous robots. By adding modifications and unique ideas to these principles, it is believed that the ARSS will be able to perform just as effectively as its predecessors.

3.7 Proposed Design

The proposed design for the ARSS will utilize the Roomba Create 2 platform. It will consist of a powerful two wheel drivetrain and a charging station. To facilitate the robot's maneuverability around the customer's backyard, the ARSS will be fitted with multiple sensors. These various sensors will be able to detect any objects it might collide into, determine if it has rained recently, and avoid any sharp drops that might damage the robot.

Another design standard that will be implemented to the ARSS will be to keep its entire critical electrical components waterproof. In doing so, this will ensure that the components won't get damaged while the sprinkler head is running. Also, because the ARSS will mostly remain outdoors, it will be manufactured with high grade materials to certify the robot will have a long life.

The sprinkler system on the robot will consist of a rotating sprinkler head, rotating base, hose retrieval system, and a variable water valve. The rotating sprinkler head was chosen because it is the most efficient and versatile way to water an area. The variable water valve helps conserve water as well as give the customer freedom to adjust the effective range of the ARSS sprinkler depending on the size of their yard. In order to prevent the ARSS from tangling itself with the hose, the sprinkler head will be attached to a rotating base which will originate from the center of the robot. This rotating base will be attached to the robot with a sealed roller bearing to allow it to rotate with minimal friction. The hose retrieval system will consist of a torsional spring that will allow the robot to move freely while keeping enough tension so it can recover the hose.

As previously mentioned, the robot will be programmed to determine where it is in relation to the charging station, while avoiding collision with objects and falling down steep slopes. It will also be able to conserve water by turning off the water supply if it gets stuck in one location for a long period of time. The customer will be able to monitor the status of the ARSS on their Apple or Android device. Within the application, multiple programmable irrigation profiles can be created if there is more than one area that is to be watered.

4. Project Management

4.1 Overview

The Autonomous Robotics Sprinkler System's three key areas of design will be: hardware testing and integration, programming and user input, and finally electronics modification and integration. Hardware and electronics modification are two different fields that will eventually be conjoined together to complete the final design. Programming however is a separate task without requiring as much input from the hardware and electronics areas as these do not directly affect the code itself.

4.2 Breakdown of Work into Specific Tasks

The breakdown of the individual tasks for hardware, electronics, and programming will be as follows. For hardware, chassis modification to the Roomba will be made in order to help for traversing grass and small obstacles. This will include possible motor upgrades, wheel tread/size changes, any alterations to the frame of the robot when incorporating the various sensors, and waterproofing electronics inside.

The sprinkler system which includes a servo motor to control the effective radius, water flow sensor, hose retrieval, and payout system must be designed. This system will be modeled after the electric cord retrieval systems employed on large yachts and commercial vessels in the marine industry. The system will include a motor to payout and retrieve the hose, a limiting switch to start and stop the motor in conjunction with the movements of the ARSS, as well as a receptacle for storing the hose when not in use.

The docking station for the ARSS will be a modified, more robust version of the Roomba chassis' original docking station designed for outdoor use. This will include waterproofing the system, creating a platform for the ARSS to rest on while not in use so as to avoid mold and outdoor degradations to the system.

In terms of electronics, the ARSS will incorporate sensors such as humidity, temperature, barometric pressure, fall/flip over, and collision detection. These sensors and servos will be controlled using the Arduino Uno microcontroller. This is where the hardware and electronics will become integrated piece by piece as the microcontroller as well as all of its peripheral I/Os are incorporated into the ARSS chassis. A cool, padded, and waterproof location inside the chassis will be designed and used to house Arduino Uno.

The sensors will be placed at strategic locations on the chassis so as to be able to provide optimal data for the operation of the ARSS. This will include modifying the chassis to incorporate the sensors as well as modifying the sensors themselves so that they will be able to stand up to the outdoor elements. As previously mentioned, the hose retrieval system while largely mechanical will have an electronic component in the form of a motor and a limiting switch which will be the controller for the motor itself. These will be calibrated so as to provide the proper amount of retrieval and payout tension on the hose as the ARSS waters the lawn. This system will be incorporated so as to avoid entanglements as well as keep the load of the ARSS as light as possible by not dragging any unnecessary extra length of hose that the robot will have to pull around the yard with it.

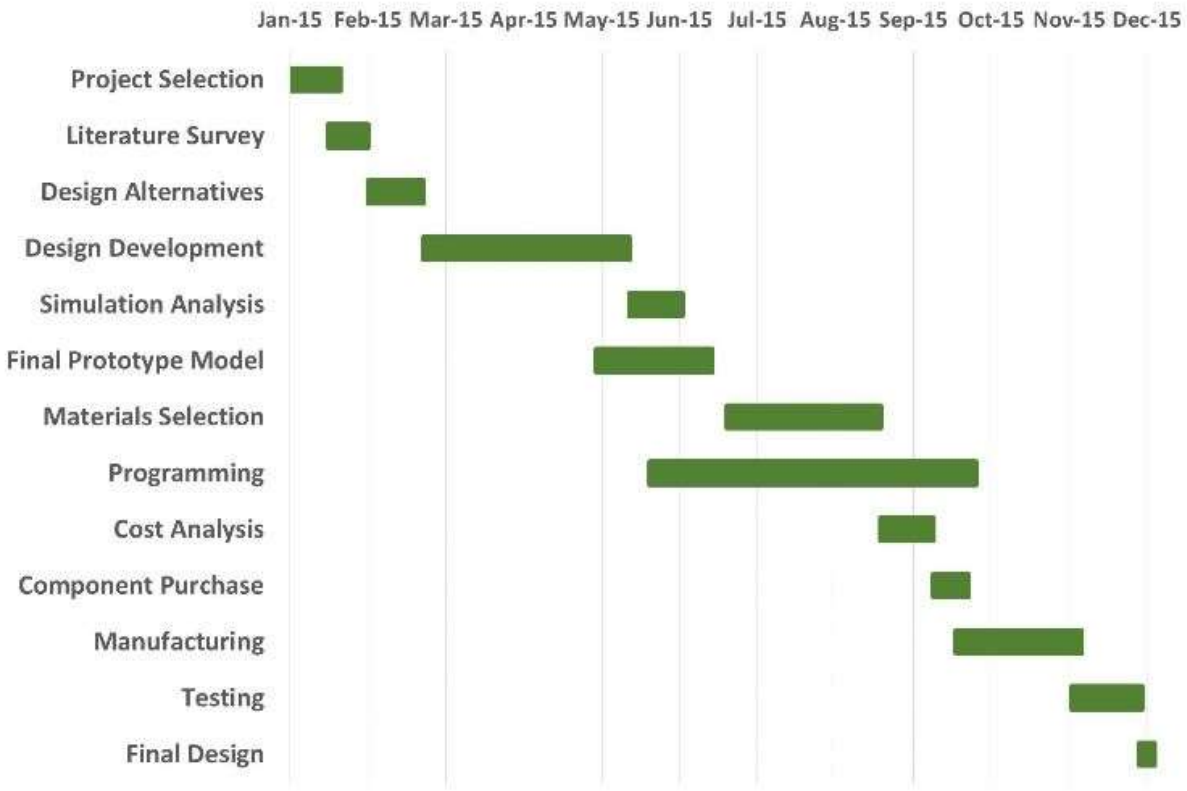
The ARSS will have a small LED screen incorporated into the ARDUINO for the initial set up. This will require a space to be made on the ARSS chassis for the screen as well as weatherproofing the screen so as to protect from outside contaminants.

Since these electrical components will be utilized, there will be a significant amount of programming. All programming for the Arduino will be done in its native language (Arduino Software IDE), and any supplemental programming will be done in C++. The Arduino Uno will be programmed to interface with the built in sensors on the Roomba chassis as well as the directional and memory functions of the system. These systems are critical for determining and executing the watering pattern for the end users yard. The Arduino will be programmed to receive inputs from the sensors and subsequently control the ARSS based upon the temperature, barometric pressure, and humidity. The temperature and humidity sensors will be used to deactivate the ARSS on wet, rainy days so as to conserve water and protect the lawn from overwatering. The ARSS will be programmed to provide a simple one time user interface for

initial set up. This set up will have the user input: lawn size, watering intervals, path of watering and obstacles in the lawn.

4.3 Gantt Chart for the Organization of Work and Timeline

Table 1: Gantt chart



4.4 Breakdown of Responsibilities among Team Members

Armando Camacho.

Major Role: Programming, Support Role: Electronics and Hardware.

Armando will be the leader and primary programmer for the Arduino Uno and Roomba chassis. This will involve programming the Arduino to recognize and utilize all sensors for the system and incorporate them into the everyday function of the ARSS. Other tasks include writing the end user initial set up program as well as the internal operation code for the ARSS itself as described in section 4.2. Armando will be supported by Frank Azcuy, and Benjamin Sturman.

Frank Azcuy.

Major Role: Electronics, Support Role: Programming and Hardware.

Frank will be the leader and primary integrations specialist for all of the electronics that will be place in and on the ARSS. This will involve the calculation of power levels, conversions, wiring, collaborating with Benjamin on the hardware side to ensure all parts fit, collaborating with Armando to ensure all programming is synchronized as well. Support will be provided by Armando Camacho and Benjamin Sturman as required.

Benjamin Sturman.

Major Role: Hardware, Support Role: Electronics and Programming.

Benjamin will be the leader and head designer on the chassis modifications as well as the preparations and calculations of all the parts used on the ARSS. Weatherproofing and waterproofing all the electronic components of the ARSS, preventative measures (lubrication and greasing) for metallic and moving parts. This will involve the calculation of strains and stresses

on the vital areas of the system such as motor shafts, wheels, bearings, hose attachments, hose retrieval system, and couplings. Other duties will include the design and integration of the hose retrieval system where he will work in conjunction with Armando to design the electrical systems involved. Finally, any hardware on the original Roomba chassis which needs to be replaced or redesigned for outside use will be his responsibility as well.

4.5 Commercialization of the Final Product

Commercialization of the Autonomous Robotics Sprinkler System will begin with initial testing within small markets. South Florida will be the initial test market, as the flat land and deep grasses that are more common will provide a solid testing background. It is believed that if the ARSS is able to operate on the deep and thicker grasses and sandy soil of Florida that it will be able to operate anywhere in the United States. Once the personal ARSS system is up and running, it can expand into other markets. This will involve approaching a company such as G3 Engineering Design Inc. who will be able to take this project and help work towards a commercial level product [13]. Once initial testing, feedback, modifications have been finished and a reliable product has been established it, will be time to take the ARSS to a commercial factory level of production.

5. Engineering Design and Analysis

5.1 Overview

In this chapter, several analyses will be conducted on the ARSS which help support the feasibility of the project as well as the design that is planned to be put into use in the first prototype. Starting with the kinematic analysis, the topic of how all moving parts and how the robot will behave during operation will be discussed followed by an animation which will provide a visualization of the discussion. Moving from the topic of motion, focus is turned to the a force analysis which will help to gain insight onto what forces the robot will be experiences as it waters a given area. These forces will place a strain on the robot so stress analyses and structural analyses will also be conducted. Deflections are also another important parameter that must be inspected to ensure that the system will behave without any excessive deformations getting in the way of normal operation.

A one dimensional flow analysis will be conducted to present all variables that need to be taken into account to make sure that the robot has a functional watering range. The last of the simulations will be a thermal simulation to study how radiation form the sun and other forms of heat transfer will affect ARSS. Material selection and a cost analysis will bring the chapter to a close and a brief summary of what the design encompasses and what the prototype will look like.

5.2 Kinematic Analysis and Animation

There are four main focuses of kinematic analysis within the ARSS: the rotating support shaft, the sprinkler base plate, the sprinkler head, and the hose reel system.

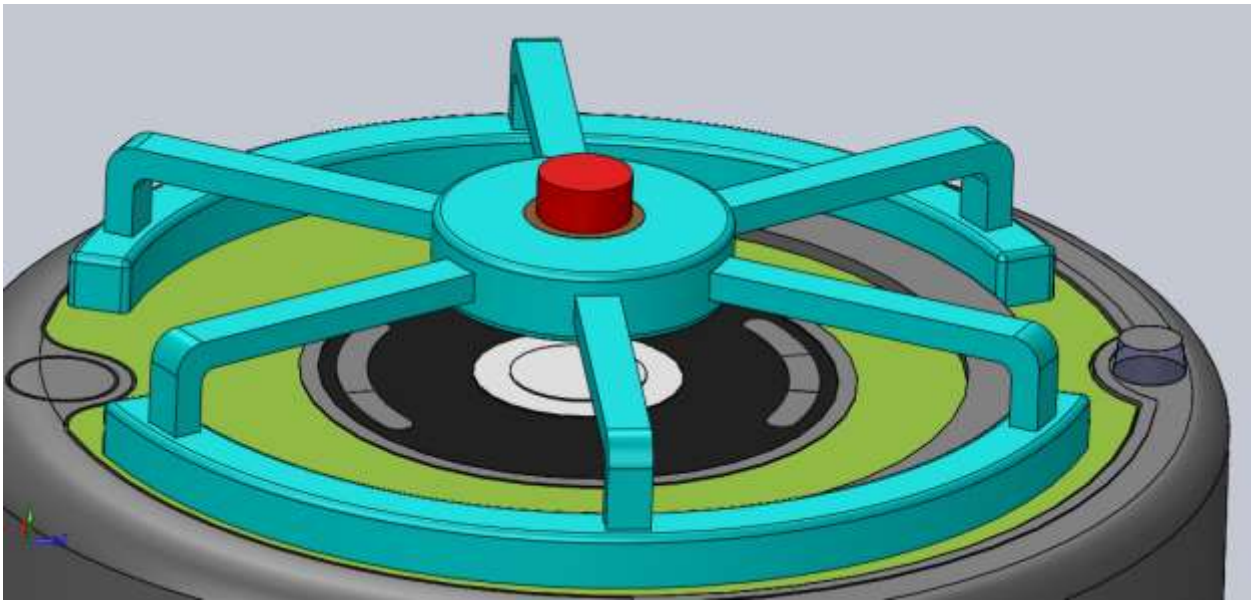


Figure 8: Rotating Support Shaft into a Bearing within the Sprinkler Mounting Bracket

The rotating support shaft (pictured as red) is shown in Figure 8. It will consist of a central shaft located inside a roller bearing (pictured as a brown part) which is placed inside the sprinkler mounting bracket (pictured as a cyan part) and will be mated to the robots chassis. This will allow for the rotation of the sprinkler base plate which will be located above the shaft. As previously mentioned, allowing the robot to move about while keeping the hose always directed at the water source is an important objective to keep kinking and entanglement from occurring.

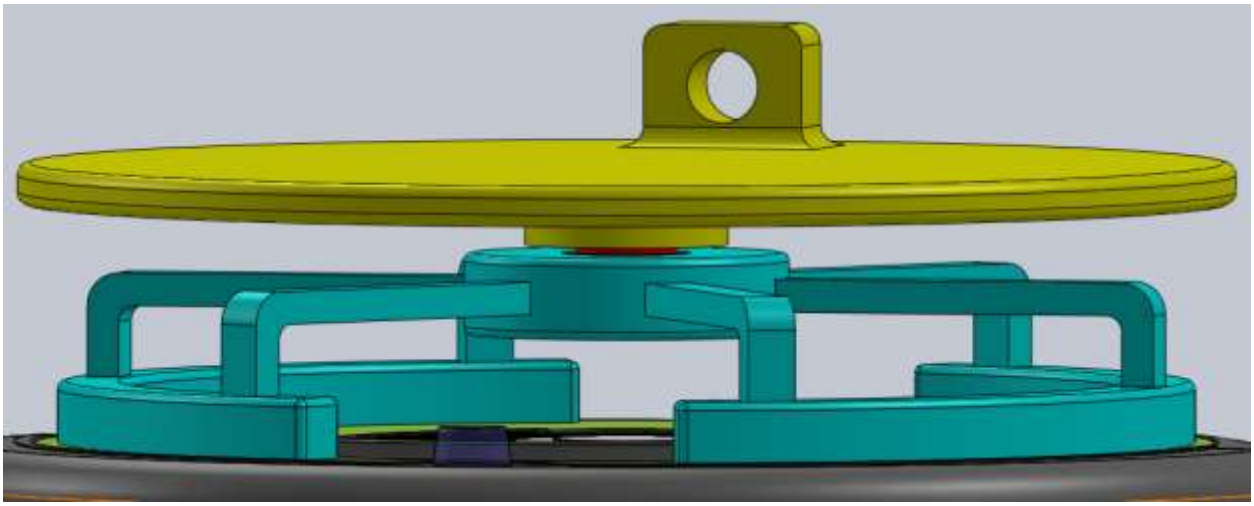


Figure 9: Sprinkler Base Plate Shown in Yellow

The sprinkler base plate (pictured yellow) is a disk which will house the sprinkler head on the top and is shown in Figure 9. The six armed sprinkler mounting bracket (cyan) will hold the support ring for the bearing itself. The main focus of this kinematic portion of the ARSS system will be on the bearing as it is the only actual moving part. The sprinkler base plate will be attached to the support shaft will be able to swivel as the robot turns due to the roller bearing. This swivel ability will ensure that the hose will always point towards the water source thus preventing kinking. This will allow the robot to make any necessary movements without entangling itself within the supply hose as well. Figure 10 illustrates the bearing to be used.

Figure 10: Roller Bearing to be used in Shaft

The sprinkler head is a commercially available rotary sprinkler head which will rotate in accordance with the pressure and flow rates of the system. A higher pressured residency will allow a higher range for the ARSS to project water around its radius due to increased rotation speeds of the sprinkler head.

The hose reel system consists of a flat hose reel, swiveling mounting bracket, Arduino Uno Microcontroller and a general purpose motor. This reel system will rotate clockwise and counterclockwise unreeling and reeling in the hose as the ARSS moves about the yard. The motor, gears, and shaft will all be under varying degrees of stress due to rotational forces. The motor will provide the torque required to turn the reel and the gears will provide the speed reduction necessary for slow even reeling.

5.3 Force Analysis

The main issue that will be analyzed in this project in terms of force analysis will be the force imparted on the housing that the sprinkler will ultimately rest on. The main source of forces and stresses that can prove to be of any cause in structural failures will be the weight of the hose as the robot moves along its path.

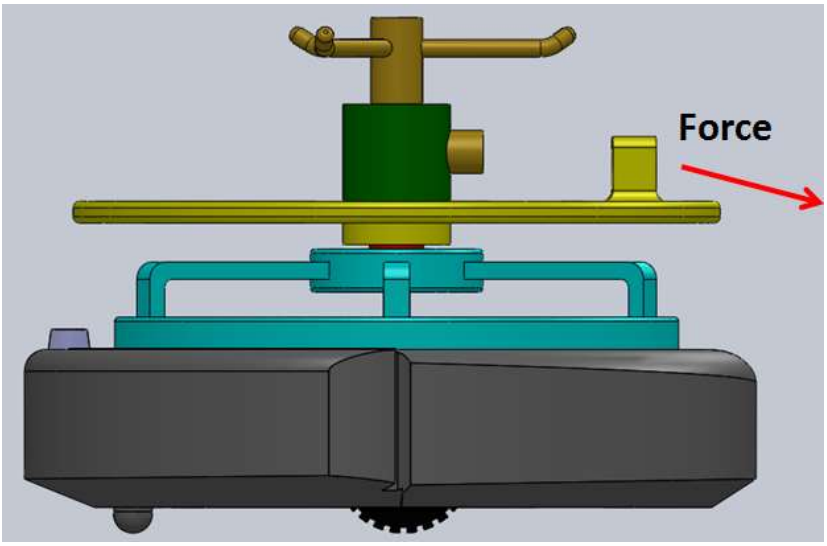


Figure 11: Force Vector on Robot Sprinkler Structure

The force can be modeled as a vector that is pointing towards the ground at an angle. This force comes from the frictional effects that the hose will experience as it slides across the ground and the angle is a result of the hose not being collinear with the fitting found on the sprinkler base plate. A lighter weight hose will reduce the friction considerably. This force will grow in magnitude as the system increases distance from the water source for two reasons. The first reason is because as the length of the hose grows longer, there is more contact area between the hose and the ground which signifies a higher frictional force. The second reason is since the hose is growing longer, the volume of flowing water inside the hose on the way to the sprinkler head

grows as well which adds to the normal force. A higher normal force on the hose leads to higher frictional forces.

This frictional force can be calculated using the following methodology:

The force that the robot experiences increases proportionally with increasing distance from the water source. While the force as a function of distance can be formulated analytically, it would be more useful to calculate the maximum force the robot feels experimentally which would coincide with the condition where the robot is farthest away from the water source. By experimentation, a unit length of hose that is full of water can be subjected to being dragged on a surface of interest. The force required to move this unit length of hose can be measured using a force gauge. This measured constant force value can then be multiplied by the total length of the hose to find the total amount of force required to drag the hose as well as the volume of water through the measured surface. This can be expressed in an equation as:

$$F_t = CL_h$$

Where F_t is the total force the robot is experiencing, C is the measured frictional constant in unit length of hose, and L_h is the total length of the hose. This simplified equation can be used for an approximate estimate at the time of maximum distance from the water source.

The angle that the force points downward is dependent on the hose material and distance but can be assumed to be 20 degrees as an average. With knowledge of the behavior of the force now quantified, structural analysis and design can be conducted.

5.4 Structural Design

The entire mounting assembly was designed not only to allow the mounting of the sprinkler head onto the system, but to also deal with the forces that were discussed in Section 5.4.

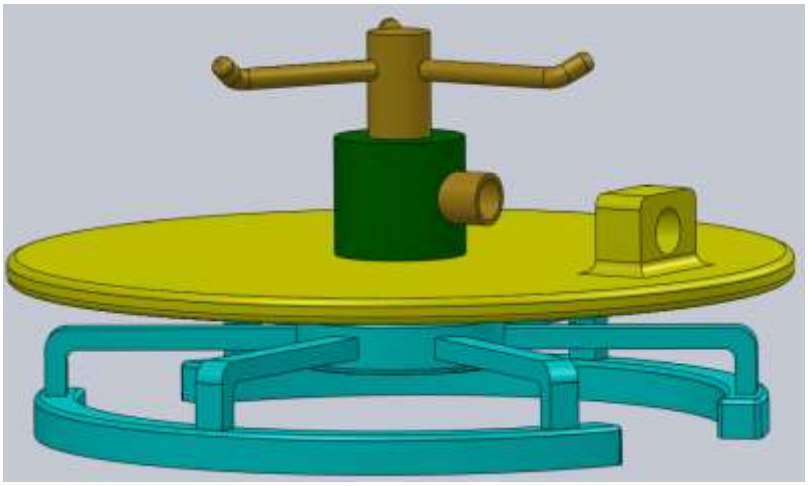


Figure 12: Sprinkler Mounting Assembly

These forces will be transmitted throughout the entire assembly and therefore, the entire system will be analyzed for points of high stress areas. The robot is not of any concern in the structural design of the system since the sprinkler mounting base is predicted to be the weakest portion of the assembly. By inspection, it is predicted that the legs connecting to the mounting base will experience the highest deflections and stress. To compensate for this, thicker cross sections being used in the six legs was kept in mind. These legs are connected to two mounting bases which will be fixed to the top of the robot. The mounting legs will also connect to a bearing fixture where the bearing will register. A shaft will connect to the inside of the bearing which is connected to base plate and at the top is the sprinkler head.

5.5 Stress Analysis

A stress analysis was conducted using SolidWorks simulation software which is a well-known FEA package. Figure 13 shows an overview of how the sprinkler mount behaves when subjected to the forces discussed in Section 5.4.

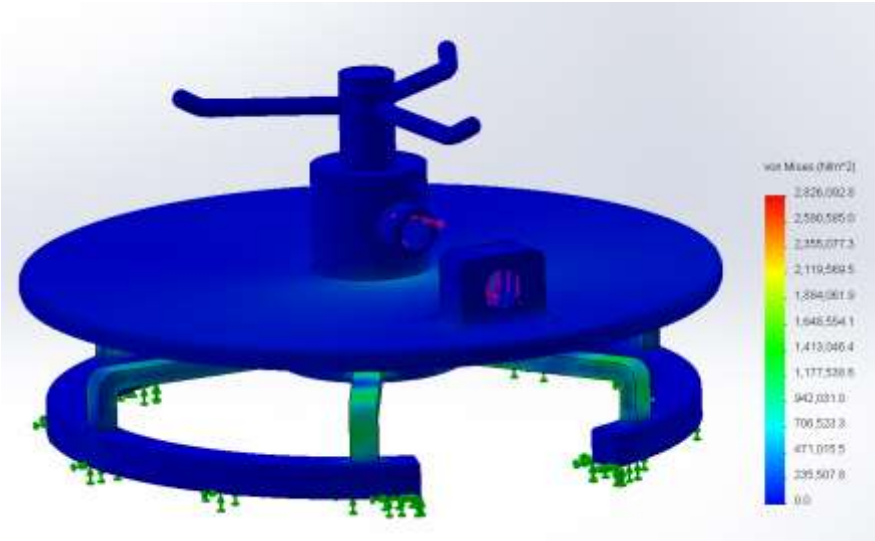


Figure 13: Stress Analysis of Sprinkler Mounting Bracket Assembly

Areas of blue show low stress and should not be paid much attention to. Attention will be turned to green areas or areas that are out of view in Figure 14.

Figure 14 shows more vulnerable areas on the assembly that should be analyzed further. Red areas denote sections of the system experiencing the highest levels of stress when compared to the rest of the model. As long as these stress values do not exceed the yield stress of the material which in this case is ABS plastic (60.6 MPa), the system will not fail mechanically.

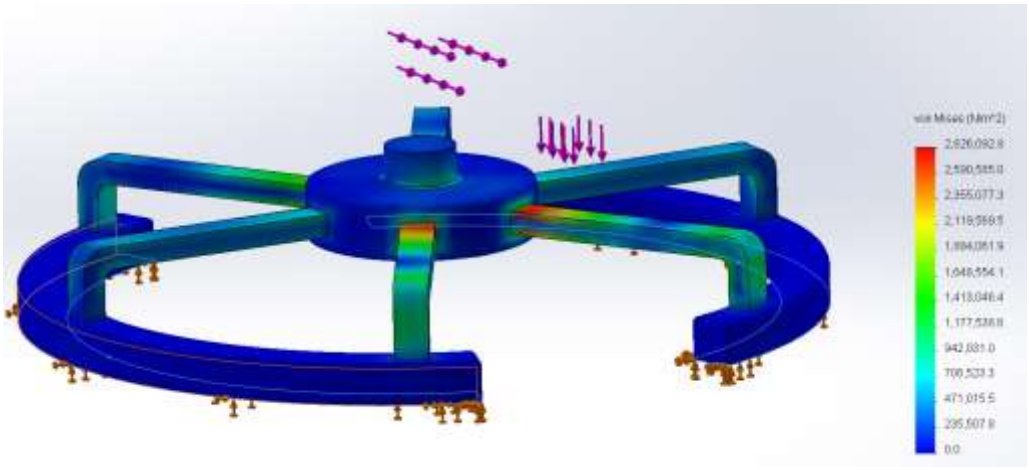


Figure 14: Sprinkler Mounting Bracket in Detail

As expected, red areas are found on the legs of the mounting bracket near the bearing support. These stresses are at 2.8 MPa in magnitude and were nowhere near yielding stress. This is a good indicator that this design can be used without risk of mechanical failure.

5.6 Deflection Analysis

Although stress analysis has been conducted and the results support that the design should function when subjected to operating conditions, deflection analysis is another important parameter that needs to be analyzed. Stresses may be at acceptable levels, but deflections can prevent the normal functioning of the assembly such as the loss of a planar surface where the sprinkler will be registered or shaft deflections that will prevent the bearing from working as expected.

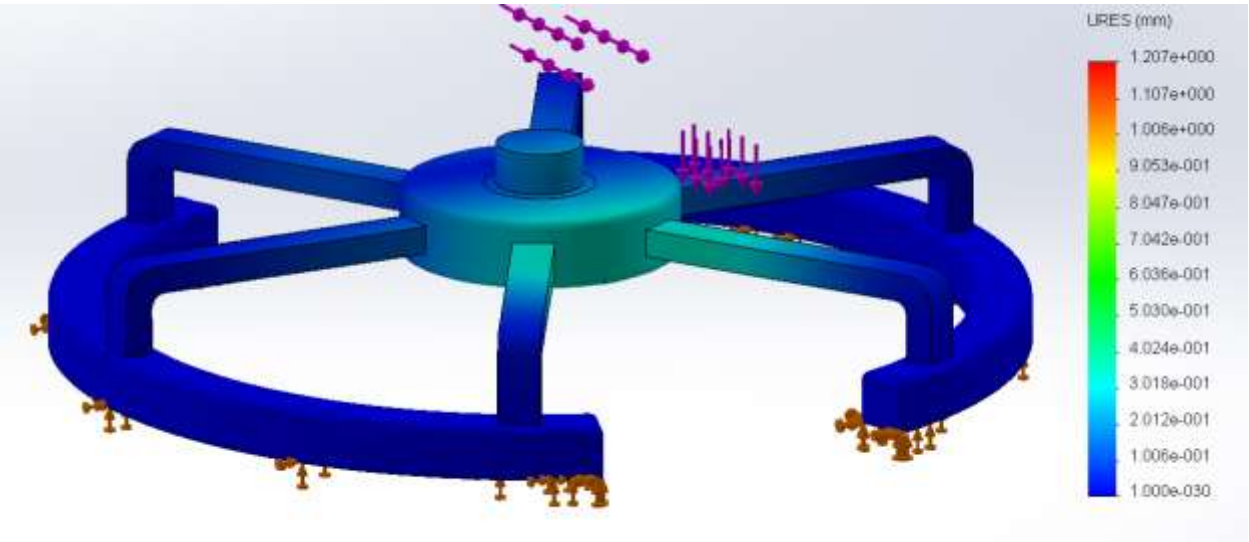


Figure 15: Deflection Analysis on Sprinkler Mounting Bracket

Figure 15 illustrates the deflections that the mounting bracket will experience during operation. Deflections for the forces experienced are roughly 0.302 mm. These types of deflections are not sufficient enough to cause failure in the mechanism. Further experimental testing can confirm these results once the prototype is built.

5.7 Flow Analysis

In order to verify that the ARSS will be able to be an effective method of watering one's yard, flow analysis is conducted. One of the first steps for this analysis is to determine the Reynolds number which will help determine if the flow is laminar or turbulent. The equation to calculate Reynolds number is shown below:

$$Re = \frac{\rho V D}{\mu}$$

Rho (ρ) signifies the density of the fluid which in this case is water which has a density of 1000 kg/m^3. Velocity (V) is the velocity of the water that comes from the home of the user at the moment the water enters the hose. The cross-sectional diameter (D) is also based off the hose of the user's house which will be equal to 5/8 of an inch. Mu (μ) is the viscocity of the fluid which is roughly 1.002 x $10^{-3}\frac{Ns}{m^2}$.

Knowing what the flow regime (laminar or turbulent) is for the fluid being conveyed to the robot is important because it is a step in determining viscous losses (or head losses) as it moves through the hose. Viscous losses occur from water coming into contact with the inner hose wall as well as mixing of adjacent layers in the streamline. These losses are impossible to eliminate so calculation of these head loss values are paramount to predicting the true behavior of this system.

Calculating head loss is done by analyzing the material of inner walls of the hose which have a roughness factor ε and can be found in the literature if the said material is known. Using ε, the Darcy Friction Factor, f, can be found which will be used to calculate these head losses. The Moody Diagram shown in Figure 16 is a simple way of finding the friction factor compared to other difficult methods which involve using long and complicated equations that don't explicitly solve for f.

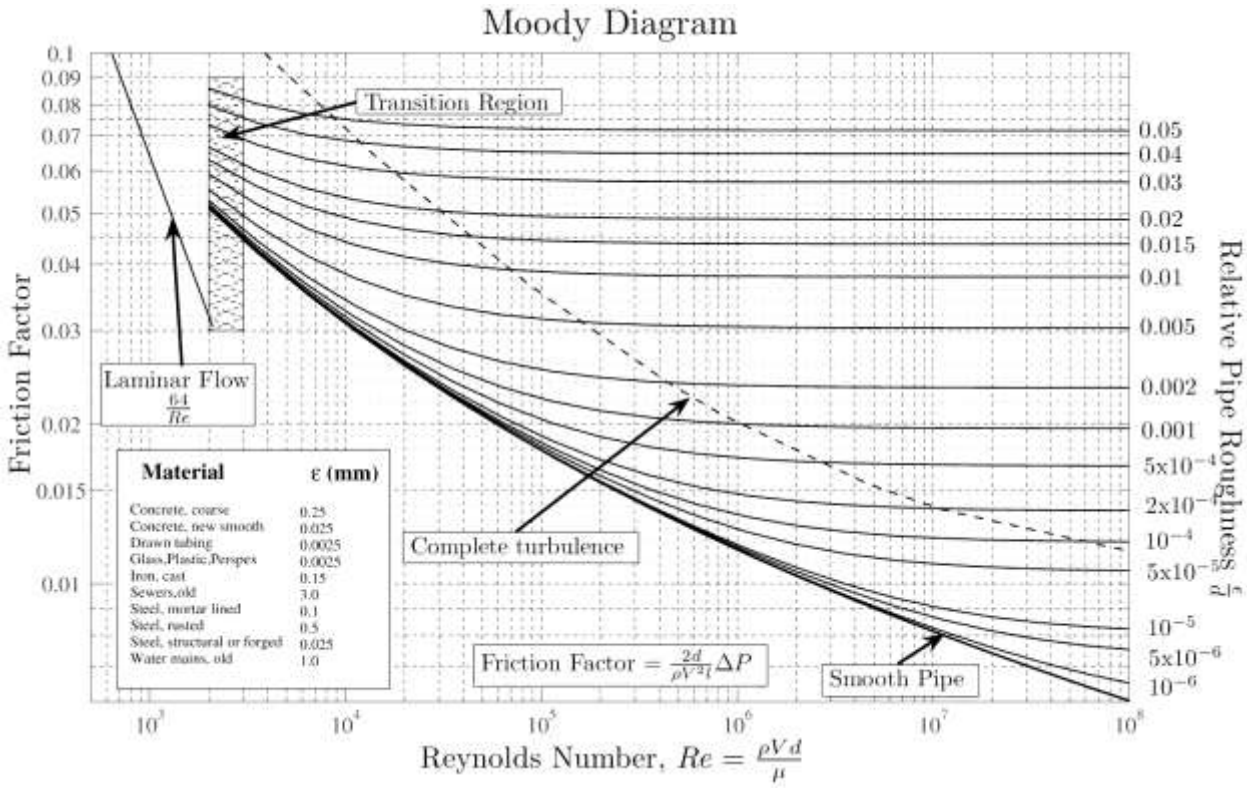


Figure 16: Moody Diagram [14]

After the Reynolds number and the friction factor are calculated, the exit velocity of the water exiting out of the sprinkler on top of the robot can be found by utilizing Bernoulli's equation for incompressible, one dimensional, steady state flow.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + (f\frac{L}{D} + \sum K_L)\frac{V_2^2}{2g}$$

All variables with subscripts of 1 represent the fluid coming into the hose from the user's home and variables with subscripts of 2 represent the fluid right before the exit of the sprinkler. Gravitational effects can be ignored due to negligible changes in elevation. The variable K accounts for losses incurred from geometric obstacles such as turns and fittings. Rearranging variables to solve for V_2 yields the equation

$$V_2 = \sqrt{\frac{2(P_1 - P_2) + V_1^2}{\rho\left(1 + \left(f\frac{L}{D} + \sum K_L\right)\right)}}$$

With the exit velocity of the water found, the predicted range of the water stream exiting the hose can be calculated.

Using the equations of kinematics for frictionless projectile motion, the maximum range of the water streams which define the effective watering radius of the ARSS can be solved for.

$$d = \frac{V_2^2}{g}\sin(2\theta)$$

Where θ is the angle of the released water stream that comes from the sprinkler head. From this analysis, it can be seen that the longer and more complicated the shape of the hose, the smaller the effective watering radius of the robot will be.

5.8 Thermal Analysis

Being aware that this system is going to be placed outside for most of its operating life, heating effects from the sun will have to be addressed and convective effects which can be a method of heat rejection. One way to counteract radiation effects from the sun which can cause excessive heating of the robot is to coat the top surface of the sprinkler base in a reflective paint to reject a substantial amount of the radiation. The sprinkler base already provides some protection from heating by acting as an obstacle and providing shade to the robots vital internals and Arduino. This extra step alongside other possible solutions such as a protective roof which will live on top of the robot's docking station can considerably reduce harmful heating effects which can cause system failure.

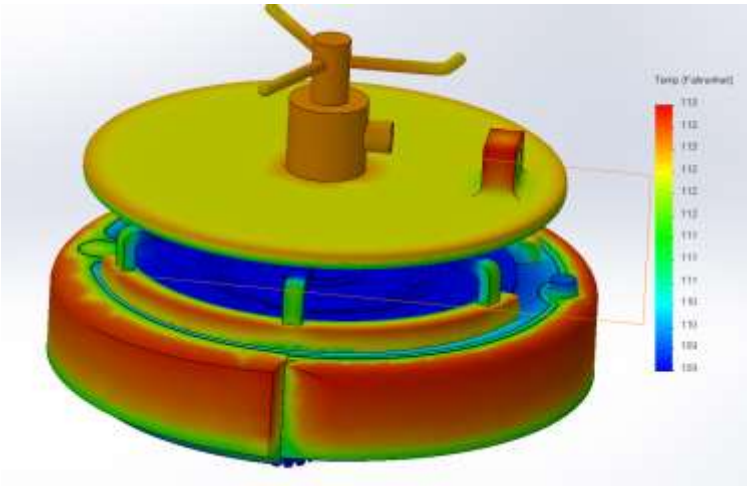


Figure 17: Thermal Study during Worse Case Temperatures

Figure 17 shows that the base plate does an excellent job in keeping the center and bottom of the robot much cooler than the surrounding areas. This is important because the electronics only function properly if temperatures are at a safe level. The outside perimeter of the robot is much hotter but this can be counteracted by expanding the base plate or using a

reflective paint. Further research will be conducted. Note that this is a worse case analysis of 110 degrees Fahrenheit outside temperature.

It is not recommended to leave the robot outside once the 100 degree Fahrenheit mark is passed as this may damage the robot permanently. As previously mentioned, a small awning that will cover the dock station can be used to further mitigate excessive heating from solar radiation. It is also not recommended to leave the robot outside in freezing temperatures as this may damage the hose system or moving parts on the robot. Care should always be taken when either temperature extreme is being experienced outside.

5.9 Material/Component Selection

Table 2: Material Selection/Design

Part	Material
Bearing	Steel
Mounting Bracket	ABS Plastic (Preference Aluminum)
Support Shaft	PLA
Guide-Plate	ABS Plastic (Preference Aluminum)
Hose Reel	Wood (Preference Aluminum)
Gears	ABS Plastic
Hose	Polyurethane
Screws	Stainless Steel
Adhesive	Epoxy Resin and Fiberglass Cloth
Robot	Roomba Create 2
Hose Connection	Aluminum/Brass
Water Seal	Rust-Oleum NeverWet

The mounting bracket, guide-plate, and gears will all be made of 3D printed ABS plastic. This is for prototyping purposes only and once the product reaches production on a larger scale, the material of choice would be aluminum due to its resistance to corrosion and light weight. Aluminum does not rust under water, it only corrodes. Corrosion on aluminum is far easier to circumvent with the proper preventative measures. The choice for each material was a mix of economy and durability. Economy due to the fact that this system is meant to be a low cost

alternative to a conventional sprinkler system, and durability that this is a low cost product not a cheap one.

The bearing was chosen not only for its strength, but for its roller bearing design which will house the support shaft and allow the sprinkler base to rotate unhindered by avoiding pinch and stress points that a traditional ball bearing would induce.

The hose reel which will be a single groove fire hose style reel will be made from wood initially, however in full production it will be made of aluminum for the same lightweight and durability reasons as previously mentioned.

The Roomba robot was chosen due to its durability, programmability, and built-in sensors. Many of the built-in functions of the Roomba will be able to be utilized via the Arduino thus negating lengthy programming and design time. The Roomba itself will be fully waterproofed and sealed against the elements using Never Wet.

The screws and adhesives used will be stainless steel and epoxy resin and fiberglass cloth. The stainless steel screws will be used for their strength and resistance to rust. The epoxy resin and fiberglass cloth will be used due to its high strength, heat resistance, and overall durability under wet or dry conditions.

5.10 Cost Analysis

Table 3: Cost Analysis

Part	Quantity	Unit Cost	Total ($)
Roomba	**1**	**$160**	**$160.00**
Arduino	**2**	**$40**	**$80.00**
Bearing	**1**	**$8**	**$8.00**
Plastic Material	**1**	**$50**	**$50.00**
Gilmour Sprinkler Head	**1**	**$10**	**$10.00**
Clear-Flow Hose	**1**	**$60**	**$60.00**
RGB LCD Display	**1**	**$18**	**$18**
Mini-DIN Connector	**1**	**$12**	**$12**
Liquid Flow Meter	**1**	**$12**	**$12**
Ultrasonic Range Finder	**1**	**$30**	**$30**
Velcro	**1**	**$6**	**$6**
Hose Reel	**1**	**$10**	**$10**
		Total Cost:	**$456.00**

5.11 Design Overview

Now that the required analyses have been conducted, a simple overview of the design will help clarify design intent and what is planned for the prototype. To begin, the Roomba Create 2 will be the chassis of the system which contains the programming to be an out of the box capable project. On top of the robot will be the sprinkler mounting bracket which will help register the sprinkler head to the top of the robot. The Sprinkler on top will be able to rotate freely and sits on a rotating base which will prevent tangling. The robot will be treated with chemicals that will make the robot water resistant and painted with reflective paint to reduce heating effects from the sun. The robot will be connected to motorized hose reel which will release or take in hose so there isn't excess hose in the area that the robot may entangle itself with or add unnecessary weight. It will be able to dock itself as well and most importantly, autonomous with minimal maintenance.

6. Prototype Construction

6.1 Description of Prototype

The Autonomous Robotic Sprinkler System is a sprinkler system designed to have a low visual/spatial footprint while providing all the benefits of a traditional sprinkler system. Various sensors will be attached to the chassis and incorporated into the ARSS system. These sensors will supplement the ones already present in the Roomba chassis. These sensors broaden the ARSS's detection capacity and safety features. The chassis itself was modified to house the sensors. This involved drilling into the chassis so as to provide proper housing for the sensors. The sensors are secured to the chassis by epoxy resin along with rubber seals to prevent water damage.

An Arduino Uno micro controller which communicates between the sensors and the built-in iRobot systems was incorporated into the Roomba chassis as well. The portion of the Roomba which used to house the rotary carpet cleaner was removed and the now houses the Arduino Uno. The largest modification to the Roomba chassis was the addition of the sprinkler and sprinkler support. The support is attached to the top of the Roomba itself and the sprinkler head is subsequently attached to it. These components in conjunction with a motor driven hose reel system make up the Autonomous Robotic Sprinkler System.

6.2 Prototype Design

The Autonomous Robotic Sprinkler System's construction revolves around the Roomba Create 2 programmable chassis. This chassis houses all the sensors used on the ARSS. These sensors include a distance sensor and a force sensor. These sensors will be constantly monitoring the ARSS's position as well as tension on the hose connection in order to avoid obstacles and potential tipping of the chassis itself. The bin housing the vacuum portion of the Roomba chassis was removed and a custom one was 3D printed to replace it. The space formerly occupied by the vacuum now houses the Arduino Uno microcontroller.

Figure 18: Arduino Housing

The Arduino microcontroller is the communications link between the Roomba's built in systems and the added sensors. The Arduino will communicate with the Roomba through the use of the chassis' built in serial cable. The Arduino controls the pathing, movement, flow control valve, as well as the hose reel system. Based upon the size of the yard itself the Arduino will adjust the pathing layout as well as the flow rate of the water for the sprinkler head.

The chassis has been fitted with a base to support the hose connection and sprinkler head. This base consists of two semicircular bases of which 6 legs (3 to a base) are attached. These legs then converge and attach to a circular central hub which houses the bearing that the plastic

support pipe is press fitted into. This vertically aligned plastic shaft supports the circular base plate which in turn supports the hose attachment as well the sprinkler itself. The plastic shaft is press fitted into a bearing so that as the ARSS travels and adjusts its path the hose support is able to swivel so as to always have the hose pointing towards the hose reel. This reduces the tension on the support assembly while simultaneously avoiding hose entanglements.

Figure 19: ARSS Chassis

The sprinkler itself is a Gilmour stationary sprinkler and is attached to the previously mentioned rotating circular base plate. The sprinkler is attached to a valve which controls the flow rate of water from the hose. The valve is controlled by a small DC motor, and the motor itself is controlled by the Arduino Uno. This valve allows for the reduction or enhancement of the overall watering diameter of the sprinkler head.

The hose reel system consists of a plastic 1 inch wide reel of which the Clearflow collapsible hose reels and unreels from as needed by the ARSS. This reel will be attached to the house by swiveling mount so as to allow for the tension of the hose to always be in a direct line between the ARSS and the reel itself. The reel is controlled by a DC motor controlled by a second Arduino microcontroller that communicated with the one of the ARSS. The reel will

wind out as the ARSS is heading out to water and will rewind as it comes back to dock. This will alleviate tension as the ARSS heads out and lightens its load as well as entanglements as it heads back to its dock. The Clearflow collapsible hose also aids in lightening the load by empting itself of water while the ARSS is moving around the yard, thus becoming lighter and easier to transport.

6.3 Parts List

Part Picture	Description	Quantity	Company
	Roomba Create 2 Programmable Robot	1	iRobot
	Gilmour 1225 sq. ft 8-Pattern Stationary Sprinkler	1	Gilmour
	HK2512 Needle Roller Bearing 25mmx32mmx12mm	1	VXB
	Clear-Flow Garden Hose 5/8”	1	Clear-Flow
	Sprinkler Support 3D Printed PLA	1	Self-Produced
	RGB LCD Display Kit	1	Adafruit
	Liquid Flow Meter	1	Adafruit
	Mini-DIN Connector Cable	1	Tensility

	LV-EZ Ultrasonic Range Finder	1	Maxbotix
	Industrial Velcro	1	Home Depot
	Hose Reel	1	Self- Produced
	Arduino Uno Board	1	Arduino

6.4 Construction

The Roomba chassis is the base for the construction of the ARSS as shown in Figure 20.

Figure 20: ARSS Chassis

The chassis was initially modified by using a custom 3D printed bin tray to replace the factory bin tray that originally housed the vacuum portion of the robot. This custom tray was screwed in place by stainless steel screws and now houses the Arduino Uno. The Arduino is held in place as well by small stainless steel screws in order to prevent unnecessary jostling or damage that is expected from the movement of the ARSS. This modified printed bin tray is shown in Figure 21 alongside the completed electrical wiring.

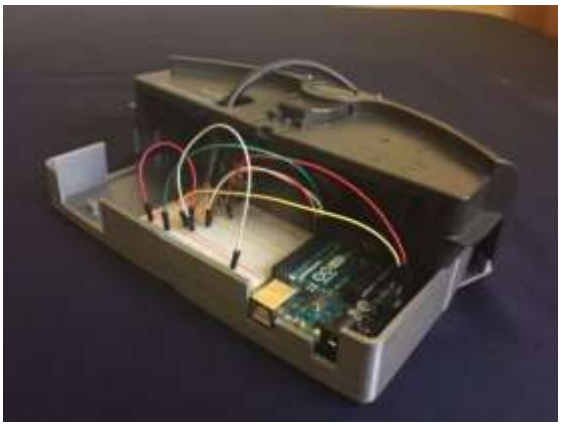


Figure 21: 3D Printed Bin Tray and Wiring

The sprinkler supports and bearing base were assembled by first sanding each of the pieces so as to remove any burrs or rough patches left during the printing process. This allowed for a smooth fit as well as roughed up the edges to allow for the epoxy resin to have a secure hold on the pieces. Epoxy resin was used due to its strength, durability, and its resistance to mold and water damage. The center of the sprinkler support was first fitted with the needle roller bearing along with the press fitted plastic shaft. Figure 22 shows the tapping of the sprinkler base onto the webbed shaft which goes into the bearing and bearing base.

Figure 22: Tapping of Sprinkler Base

Figure 23 shows the finished product which will be placed on top of the robot. Note that it is upside down for illustrative purposes. This stand is able to rotate freely.

Figure 23: Sprinkler Support Structure

Once these parts were assembled, the sprinkler platform was attached to the plastic pipe as well. Once the entire sprinkler assembly was completed it was then securely attached to the top of the iRobot chassis by industrial strength Velcro. Figure 23 shows the sprinkler structural assembly attached securely onto the robot chassis.

Once the main assembly is finished, it's time for the accessories such as sensors and displays. Figure 24 shows a 16x2 LCD screen that is fitted onto the assembly to read out diagnostics information, water usage and if time permits a scheduler for times that are desired for yard watering.

Figure 24: 16x2 LCD Screen

A flow meter which is attached right before the sprinkler shown in Figure 25 will measure how much water is being consumed for every watering cycle and current water usage during operation.

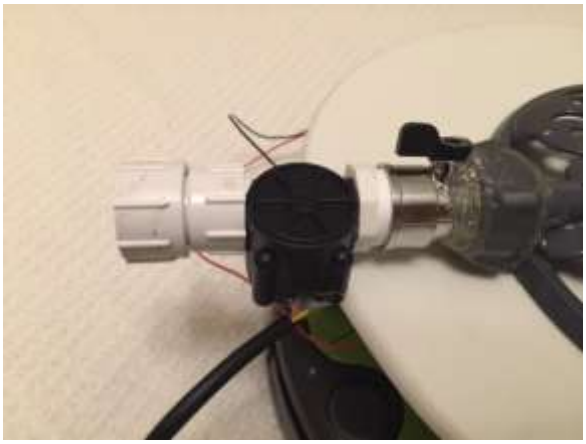


Figure 25: Digital Flowmeter

Figure 26 shows a distance sensor which will be used to tell the robot where it is situated and to see obstacles up to 10 feet away. It is placed in front of the robot to prevent collisions without having to bump into an obstacles.

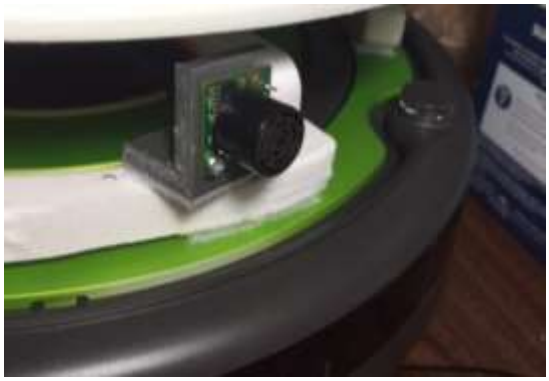


Figure 26: Distance Sensor

Figure 27 shows the entire ARSS system as it will be tested and experimented on. As mentioned before, it is a prototype and a work in progress so more features may be added in future work.

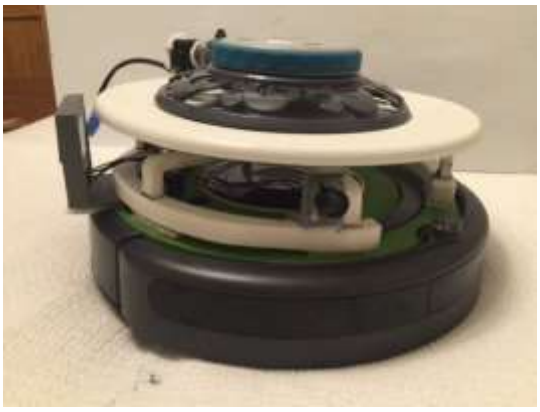


Figure 27: Completed Assembly

There are other sensors on the robot as well that will be used such as the cliff detectors and bump sensors that will not be included in this report, but can be found in the User's manual available at the iRobot website.

All electronics used in this project were prepared with a water resistant coating of Never-Wet by Rust-Oleum. This coating will protect the internal and external electronics from any possible water leakages or condensation that may occur within the system itself. The chassis itself was sealed using a combination of epoxy resin and GE Ultra Glaze.

The hose reel system for the Autonomous Robotic Sprinkler System will consist of a typical fire hose style reel controlled by a motor and small microcontroller. This reel will be attached to the wall of the user's home just like any other hose reel; however the ARSS hose reel is mounted on a swivel. This swivel is so that as the ARSS travels around the lawn that the hose will always be pointing directly towards the ARSS itself. This will reduce kinking of the hose as well as tension and force required to pull the hose by the system itself. The reel will receive signals from the ARSS to unravel as the ARSS travels away from the reel and to ravel as the ARSS travels towards the reel. This again will minimize entanglements with obstacles in the yard and system as well as reduce the force required by the ARSS to move the hose about the yard. The hose used is a collapsible hose just like a traditional fire hose and is made of non-toxic material. The motor used is a small DC motor located at the central axis of the hose reel and is controlled by a small micro controlled switch. This switch receives its input from the ARSS itself via wireless communications received through an antenna.

6.5 Prototype Cost Analysis

The prototype is going to be designed and manufactured similar to the cost as previously shown. The cost breakdown for the prototype is shown in the table below.

Table 4: Prototype Cost Analysis

Part	Quantity	Unit Cost	Total ($)
Roomba	1	$160	$160.00
Arduino	2	$40	$80.00
Bearing	1	$8	$8.00
Plastic Material	1	$50	$50.00
Gilmour Sprinkler Head	1	$10	$10.00
Clear-Flow Hose	1	$60	$60.00
RGB LCD Display	1	$18	$18
Mini-DIN Connector	1	$12	$12
Liquid Flow Meter	1	$12	$12
Ultrasonic Range Finder	1	$30	$30
Velcro	1	$6	$6
Hose Reel	1	$10	$10
		Total Cost:	**$468.00**

6.6 Programming and Path Finding

So far, Chapter 6 has discussed the mechanical design of the ARSS system, but one important subject that is just as important is the programming. One challenging dilemma that faces the design of this system is the fact that it will be an autonomous irrigation robot and being autonomous means that minimal user input is required in order to operate. Goals in autonomous behavior would be object avoidance, preventing kinking in the hose and the ability to be scheduled for watering cycles throughout the week. Section 6.6 will talk mostly about the path finding algorithm used to water a set area and the procedures required in order for the program to work correctly which includes first time set up and certain things to avoid allowing normal functioning of the ARSS.

To begin, in order for the ARSS to know what size of the area it will be watering, it will have to be user inputted. After this is done, the ARSS will automatically calculate an array which will represent the yard. This is shown in Figure 28 as follows.

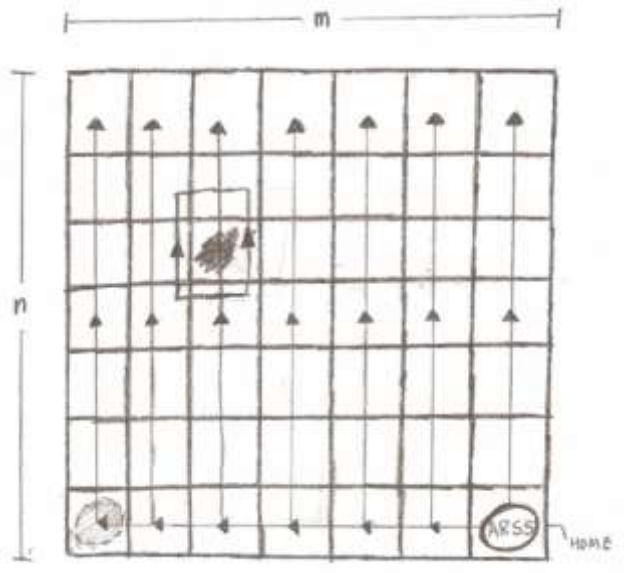


Figure 28: Pathing Diagram Array

This array is calculated by taking the dimensions input by the user and dividing them by the watering radius. This will create an m by n array which can be declared as an array data type in the program that runs the algorithm. The array location that the robot considers home must also be declared in order for the robot to know where it is situated in the area and as an example, the home array element is set at the most bottom right. Once this is set, the robot will begin by watering the column of each array. Each array element starts with a value of zero which is considered false. Any array with the value of zero means that that area has not been watered just yet. Once the robot passes through the array coordinate, it means that the location was watered and the array which represented that area will be given a value of 1 or true. The robot will then know that this spot has been watered. The speed at which the robot drives itself will be determined by the flow rate which is given by the flow meter on the ARSS and the water requirement set by the user. More water means that the robot will move slower and less watering means that the robot will move faster before marking all the array values as 1 and returning to base.

In the event that the distance sensor begins to read an obstacle as shown in figure 28 as a dark shape on the top left of the array, it will notify the robot and a sub-routine will tell the robot to either steer left or right. This decision is made depending on which side the ARSS's home is set at. If the hose location is to the right of the obstacle, the ARSS will go around the obstacle to the right in order to keep the hose form tangling itself with the obstacle it is trying to avoid.

In order for the robot to know its exact position in the grid, an encoder that is in the robot can be used to tell where the robot is located at all times. The encoder basically counts how many wheel revolutions have been done which gives distance if the radius of the wheels are given which in this case, it is known.

There are limitations and specific situations where this pathfinding algorithm may not function correctly. For example, placing an obstacle right next to the home of the robot may block its path completely. Additionally, having very large obstacles such as large trees or bushes in the center of the watering area will prevent the hose from moving freely from behind the robot. This is expected and as a comparison, the iRobot company also suggests the same with its vacuuming robots [16]. A much cleaner and organized yard with minimal obstacles is ideal for the ARSS to operate.

6.7 Discussion

The analysis of the construction of the ARSS was explained in detail and organized to show the steps in which we took to achieve our goal. In section 6.1 the description of the ARSS prototype and the requirements set that we wanted to accomplish. Section 6.2 goes into further detail of the various subsystems and describes how they help the prototype carries out all of the necessary functions. The following section shows all of the individual parts necessary to build the prototype. Section 6.4 shows the workflow of how the group came together to build the final prototype. Section 6.5 shows the cost analysis of the final prototype and how we were able to determine the total price for the build. 6.6 shows the programming algorithms that make it possible for the ARSS to operate. It is not a final version but it is a starting point and will be worked on in the future.

7. Testing and Evaluations

7.1 Overview

Chapter 7 will cover all subjects pertaining to the testing and experimentation of the prototype developed in chapter 6. In the design process, the actual design is just part of the process itself to create something that is truly functioning in the ways that the designer intends. More specifically, while the fit and form of a design may be met, one must not forget about the intended function. This chapter will touch on a few parameters that are necessary for the robot to function as it will face several different environments during operation. Such as stress testing on various parts of the project, battery testing to see how long it lasts in its operating environment before needing to recharge, outside temperature testing to make sure there is no danger from overheating, hydraulic testing to ensure satisfactory watering radii/behavior and a pull test to see how much weight the robot can pull before it can no longer move. Several trials will be conducted to ensure more accurate data in the long run.

7.2 Design of Experiments – Description of Experiments

It is one thing to be certain of what needs to be tested and experimented on, but the other aspect that needs to be regarded with attention is exactly how an experiment will be carried out in order to collect the data that is needed. There will be several experiments conducted to confirm that the robot will function when it is finally in the hands of the end user.

First off, stress and force testing will be conducted on the robot to make sure that none of the structural components that hold up the sprinkler will fail. Referring to the structural simulations in Chapter 5, the areas most at risk are the feet that hold the sprinkler base plate in place. For this reason, stress testing will begin here and then a second test will be at the shaft that enters the bearing and connects to the sprinkler base plate.

In order to test the legs of the assembly, a leg will be placed on a vice and weights will slowly be added until the part fails completely. The amount of weight will be recorded and the experiment will be conducted 3-5 more times for precision and accuracy. Figure 29 shows the set up for this first experiment.

Figure 29: Experiment #1 Stress Test Set-up

A second, but similar experiment will be conducted for the shaft of the assembly in order to see what magnitude of loading will cause it to ultimately fail (destructive testing) or at least ensure that it will not fail at a certain amount of weight (non-destructive testing). Figure 30 illustrates a very similar testing set up for the experiment. The black string is what will hold the weight that the shaft will experience.

Figure 30: Experiment #2 Stress Test Set-up

With structural issues addressed, attention is focused to electrical and battery testing. One important parameter that should be known is how long the battery will last before having to return to the dock for a recharge. Watering different parts of a lawn at different times may cause problems in lawn uniformity. The longer that the battery lasts, the larger an area it can water. The test will involve the robot being connected to the water source while the valve on the robot is turned off. Regular operation will be emulated by having the robot move back and forth throughout its max range of motion non-stop until the battery completely dies. This maximum distance is determined by the hose length of 45 feet. The amount of time the robot will do this and how many cycles it completes will be recorded. This will give a realistic figure on longevity of robot battery life. Figure 31 illustrates the set up for this third experiment.

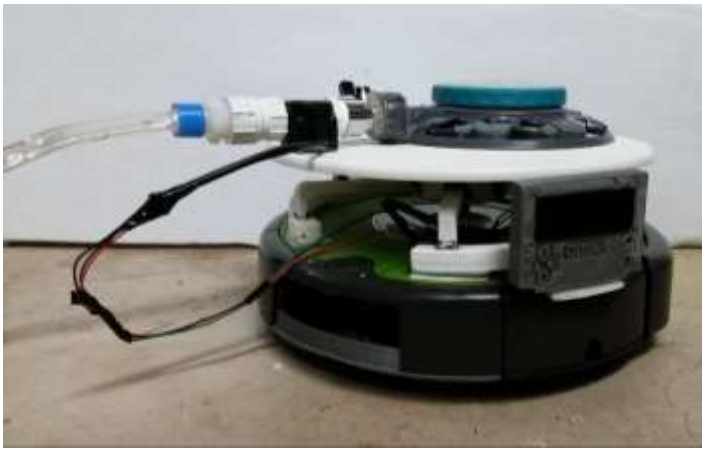


Figure 31: Experiment #3 Battery Testing Set-up

A fourth experiment which concerns the watering aspect of the ARSS system is the effective watering radius of the robot at differing distances from the water source. As discussed before, all fluid flow experiences internal friction effects and as a result, the longer a pipe or hose system is, the less pressure and velocity available at the end of the hose or nozzle. It is expected that the farther the robot is away from the water source, the smaller the radius of the sprinkler. The aim of this experiment is to verify this hypothesis and to see the magnitude of radius loss due to frictional effects as a result of maximized flow distance at 50 feet and adding another 50 feet of hose to see what the watering radius will be. Figure 32 is a set up that will help measure these effects. Figure 30 shows the set up at 50 feet.

Figure 32: Experiment #4 Watering Radius Set-up

The fifth experiment to be conducted concerns temperature issues with the robot. In detail, how heating from the sun or other external factors influence the operating temperature of the robot. Additionally, there will be a control in this experiment to see how well the sprinkler base plate which was designed to prove shading from the sun will perform. It is obvious that the base plate will promote cooler running temperatures for the robot, but the magnitude of the difference between sprinkler base plate and no sprinkler base plate is a parameter that will give insight to the effectiveness of the shade design in terms of temperature. Figure 32 will show the experimental setup which is simply leaving the robot outside during the hottest hours of the day which are typically around noon and measuring the temperature with a thermal camera. Figure 33 shows the set up with the base plate.

Figure 33: Experiment #5 Temperature Testing Set-up

The sixth and final experiment will be a qualitative assessment on whether the prototype runs or not and it will be verified by observation. If the prototype can successfully navigate through a grassy terrain while watering its surrounding area following its path and avoiding obstacles, it will be considered a successful project by the team. Providing a truly waterproof chassis is a challenge and there is a possibility that the system will fail as a result of leakage seeping into the electronic systems of the ARSS.

7.3 Test Results and Data

From the first experiment, five different legs were tested to see at what loading magnitude they would fail. This is important to know since the ARSS can be pushed to a certain point knowing when failure is eminent. Using the set up displayed in Section 7.2, the plastic legs were tested until failure as shown in Figure 28.

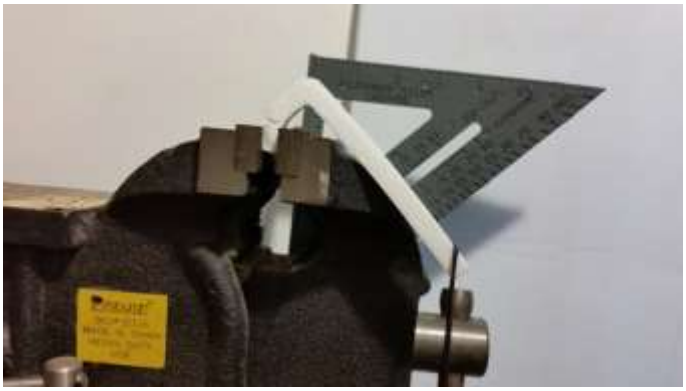


Figure 34: Experiment #1 Resulting Failure

Figure 34 shows the deviation in angle before failure and it can be noted that there is a large crack formation right at the support as expected for what can be considered a cantilever beam. Cantilever beams experience the highest stresses right at their supports. Table 4 shows that five different leg specimens were tested and all failed at roughly the same loading.

Table 5: Experiment #1 Testing Results

	0 lbs / 0 kg	3 lbs / 1.4 kg	6 lbs / 2.8 kg	9 lbs / 4.2 kg	12 lbs / 5.6 kg	15 lbs / 7 kg	Units
Leg 1	0	0.7	0.9	2.5	4.1	VMF	**mm**
Leg 2	0	0.7	1.3	2.5	4.4	VMF	**mm**
Leg 3	0	0.6	1.4	2.6	4.7	VMF	**mm**
Leg 4	0	0.5	1.3	2.8	4.3	VMF	**mm**
Leg 5	0	0.8	1.9	2.8	4.5	VMF	**mm**

Experiment #2 does not have much data to display, but the most important thing is that the part did not fail when exposed to high loadings. Figure 35 shows a qualitative analysis of a non-destructive test of the shaft. At 28 pounds, the shaft did not show any measurable deflection which is 3 times less than the magnitude that the shaft will experience during operating conditions. More weight can be added, but the part was too valuable to destructively test. This experiment was successful in showing that the shaft can survive high load situations which is satisfactory for operating conditions.

Figure 35: Experiment #2 Shaft Stress Test

Experiment #3 was a simple experiment where the battery life of the ARSS was field tested. As expected from the Roomba Create 2 reference manual, battery life topped out at 1.5 hours at best. Three trials were conducted with the hose attached and a small back and forth algorithm which mimicked operating conditions was used to test battery life. Table 6 shows the results of the three trials.

Table 6: Battery Life Testing Results

	Time (hr:sec)
Trial 1	1:18
Trial 2	1:23
Trial 3	1:14
Average	1:18

Experiment #4 was conducted in order to determine the range of the sprinkler head that is mounted on the top of the robot. A larger sprinkler radius allows for the robot to do less moving and path finding since the water is making its way to the desired watering area. This can increase battery life and allow for the programming to make adjustments for the array size that was discussed in Section 6.6 which discussed the programming of the ARSS. Figure 36 shows the experiment in progress. Afterwards, a tape measure was used to measure where the wet spots created by the sprinkler ended.

Figure 36: Experiment #4 Watering Diameter

When measured, the tape measure gave a reading of 28 feet in diameter which is acceptable for medium size lawn applications. A higher pressure water source which can be found in larger houses can contribute to an even higher watering radius. Using a shorter hose will sacrifice flexibility, but with less distance for the fluid to experience friction, an even higher radius value can be achieved for watering.

Experiment #5 was an important test which concerned the temperature of the robot when outside. A thermal imaging camera was used in order to record the temperature of the ARSS. As previously mentioned, the temperature of the robot was taken with the spring base plate on top of the robot and again without it. It was designed to not only hold the sprinkler, but to also provide shade for the robot when outside during hot conditions. The robot was left for fifteen minutes outside in direct sunlight in order for the system to reach steady state. As a reference, the sidewalk that the chassis was measured on was 87.4 ºF. Figure 37 shows initial conditions when the robot was placed outside. One thing to note that it was a windy day so convective cooling occurred which may have impacted results by cooling the chassis off and giving lower temperature readings.

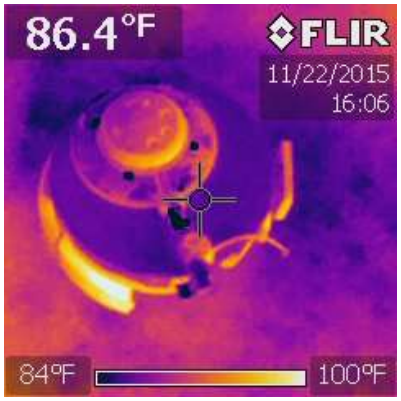


Figure 37: Experiment #5 Initial Robot Temperature with Sprinkler Base Cover

After 15 minutes, another thermal image was taken and the temperature of the assembly did not increase since the base plate is white and most of the radiation was rejected. Figure 38 shows the thermal image after the 15 minutes.

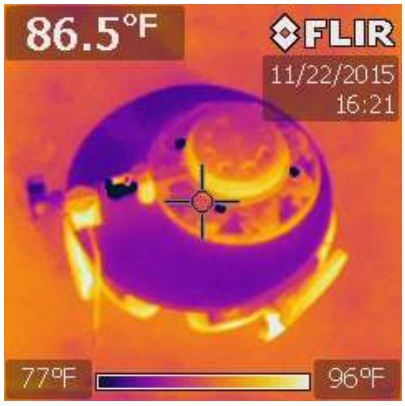


Figure 38: Experiment #5 Final Temp. Reading at 15 Minutes with Sprinkler Base Cover

Next, the base plate which provided shading was removed and the experiment repeated. Figure 39 shows the initial temperature reading of the robot.

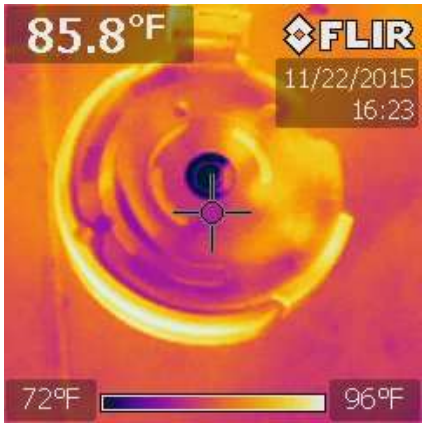


Figure 39: Experiment #5 Initial Temperature Reading with no Sprinkler Base Cover

Once again, 15 minutes were taken to allow the system to reach a thermal steady state. Figure 39 shows the final temperature of the robot.

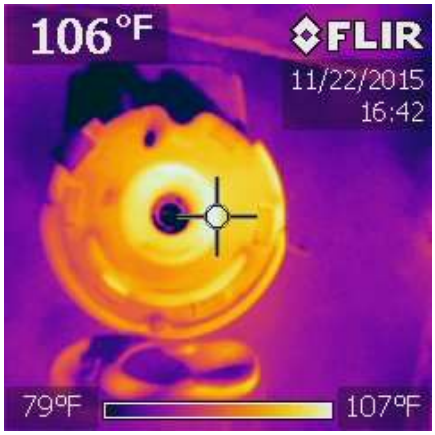


Figure 40: Experiment #5 Final Temp. Reading at 15 Minutes without Sprinkler Base Cover

Figure 40 shows that the robot reaches 106 ºF after 19 minutes. This is a temperature differential of 21 ºF which is a considerable amount. This experiment shows that the sprinkler base cover does a very good job of keeping the robot cool on even warmer than usual days. Table 7 displays the results.

Table 7: Initial and Final Temperatures

	Initial Temperature ºF	Final Temperature ºF
Plate	86.4	86.5
No Plate	85.5	106

7.4 Evaluation of Experimental Results

From the test results that were obtained, it can be said that they are satisfactory. The first two experiments which detailed how well the structural components of the ARSS behaved under high levels of loadings shows that they are very reliable for use during operating conditions. During normal operations, one can be confident that none of the structural members will fail which means that the product can be considered reliable.

The battery testing provided promising results that the robot can reliably water a sizable area without having to recharge. Not having to recharge during a watering cycle means a more consistent looking yard. Different times of the day result in differing behaviors of how plant life reacts to being watered.

The watering radius is also of a very good value. A range of 30 feet can reliable water a yard with few passes which means less work for the robot to maneuver around which decreases operation times. As said before, the watering radius can be improved by reducing the hose distance or using a higher pressure source of water. Different hose settings for the shape of the water stream can further increase or decrease the radius in accordance with the user's preference. A manual valve is also inserted into the assembly to allow a smaller radius if a yard is too small to water or is watering outside of its intended bounds.

The thermal test also gave insight into how successful the shading design was in protecting the robot from radiation heating from the sun. Even in hot weather, the cover provided good protection versus not having the cover on top of the robot. Overall, the experiments provided value in determining whether the robot was ready for its final testing.

7.5 Improvement of Design

What can be taken away from experiment #1 and #2 is that while the structural components were very strong for what was hypothesized for 3D printed parts, further improvements in the rigidity and reliability of the structure can be made by switching to plastic injection molded parts which offer even a greater amount of strength or going straight to non-ferrous metals such as aluminum which provide very good structural support and is good for dealing with outside environments which plastic may not be able to handle. Furthermore, fasteners such as screws are improved press fits can be used in order to prevent flexing of the structure which can introduce problems later on such as fatigue cracking induced by water or humidity. This may drive up price, but in the end it will be a more reliable product which offers value.

Battery life could also be used by using higher capacity batteries which could be interchanged. From what was measured in experiments, the team feels that battery life is more than satisfactory for what the team wants to do with the ARSS.

The watering radius was a respectable value which can take care of most medium sized yards. One way that the design can be improved is to use a more efficient sprinkler head to achieve a further range.

Temperature management can also be improved by using a reflective coating to reflect radiation away from the robot and using fans in the internals of the robot to remove heat from the onboard electronics if need be. Additionally, brighter colors on the chassis will help temperatures from getting to high which could harm the robot.

7.6 Discussion

This chapter highlighted the very important subject of testing. The results recorded were promising and the ARSS should perform to the expectations set throughout the report. Further design changes can be made in future work when there is the time, but the testing that has been done should be comprehensive enough to allow for a functional prototype to be created that can test well. If funding was not an issue, the project could have had more features. Nevertheless, the robot still is a work in progress and meets its basic design goals.

8. Design Considerations

8.1 Health and Safety

When designing any consumer product, there are many variables that need to be considered. Knowing ones target audience is crucial so that the product may be tailored to gain the highest sales. Insuring the highest quality is important because it promotes a company's ability to design a reliable product which in turn enhances its brand. However the most important aspect when designing a consumer product is ensuring the safety of the consumer.

The first step to help keep the end user safe while using the robot, is providing them with the necessary information of the capabilities of the robot. This is done by making sure each robot comes with a simple yet descriptive user's manual. The user's manual must also be provided in multiple languages especially if the product is one that will be sold in multiple countries. Typically, a user's manual will contain technical information about the product and how to properly use it in a safe manner. The user's manual will also show how to assemble the product if assembly or installation is required.

The design of the robot will have a robust construction and consist of various sensors to ensure that the end user is safe. Sensors incorporated in the robot will recognize proximity and cliff detection which will allow anyone to safely approach the robot and move it while it is operating. If the robot needs to be moved, it must also be built to be safe to handle, avoiding any sharp corners or moving parts that may harm the user. Due to the fact that the robot will be exposed to outside elements, the chassis which houses all of the electrical components must be completely sealed to ensure that no user could be electrocuted while it is being handled. These safety features will be incorporated into the overall design of the robot as it will be in adherence

with OSHA standards. Specifically the standards that ensure that the robot adheres to the minimum safety requirements for end users.

8.2 Assembly and Disassembly

When the ARSS is purchased, it will come fully assembled so that the consumer will only need to input the dimension of their yard and the time of day that they want the lawn to be watered. Due to the small and compact footprint the ARSS, storage of the device is fairly simple. The consumer will also need to install the charging station in their backyard near an outlet so that the ARSS stays fully charged. The assembly also comprises a retrievable hose system which is attached to an electric motor. The robot maneuvers through the yard while the hose reel pays out the hose and then retrieves it as the robot returns to the charging station. This hose retrieval system was designed for the lightweight polyurethane hose making it easy to assemble and disassemble from the device if need be. To change the hose on the robot the user must unroll the hose from the device and unscrew the end attached to the center of the hose reel. The user will then be able to take out the polyurethane hose that comes with the robot and insert a hose of their choice. Due to the fact that the original design of the robot was constructed with the lightweight polyurethane hose other hoses may or may not perform with the same capacity as polyurethane hose due to their weight.

In regards to the user assembling the robot, the only part of the robot that the user will interact with is the hose itself. The robot is manufactured in a manner that interaction with it is only needed when the user wants to check if the system is functioning properly. Due to the fact that the robot must be fully sealed to prevent water damage, it is not recommended for the user to disassemble the robot. If the consumer does need to disassemble the robot for any repairs, the robot may be taken to a local repair shop. The robot is a user friendly device that was designed to need very little maintenance from the end user. It is designed for the user to perform minimal

work in the assembling of the product in order to promote the safety of the user and optimal efficiency of the product.

8.3 Manufacturability

The original design of the ARSS did not take manufacturability into account because the basis of this project was to create a prototype to verify if this product is worth mass producing. Manufacturability will be taken into account if it is decided to continue further with the ARSS past the prototype stage. By designing the robot efficiently and with lean manufacturing in mind this will ensure that the product will be simple to manufacture. Also this will ensure not only high quality as well but will help to bring down the overall cost of the product. Currently the various parts of the ARSS were 3D printed which is quick and effective for prototyping purposes; however this method is not effective for mass production. In the future the 3D printed parts as well as the main chassis will be manufactured using direct injection molding. Direct injection molding has a very expensive overhead cost but this cost is offset as the quantity of the product increases.

In the case that the ARSS reaches the manufacturing stage there will be many changes to the prototype that will be proposed and then analyzed. As mentioned before, many parts of the ARSS were 3D printed in order to minimize cost and provide a durable material for prototyping. The materials were printed as closely to that which would be used in a manufacturing setting as possible. In the manufacturing stages these parts would be constructed out of ABS plastic due to its robust nature. ABS is a strong material that will be able to withstand the weight of the robot without increasing the overall weight of the product which would affect the efficiency of the robot. ABS will also be able to endure the environment in which the robot will function, i.e. sun, grass, rocks, and rain. ABS is also a cost efficient material that would still allow the robot to perform efficiently. Some materials that could be used would be non-ferrous metals due to their sturdiness in harsh environments; however there are also draw backs to these materials. Using

metal during construction will increase the overall weight of the robot. This added weight would slow the machine as well as minimize the efficiency of water distribution per area. Non-ferrous metals while rust resistant still do tend to corrode over time. This means that the consumer will need to replace these metal parts after certain period of time. For manufacturing purposes the materials used in the prototype should be analyzed and tested in comparison to other materials that would provide the same or better efficiency while also being cost efficient.

8.4 Maintenance of the System

The ARSS was designed to be fairly easy to maintain with the majority of the maintenance primarily focused on ensuring the electrical components are in working condition. Apart from maintaining the electrical components, structural maintenance can be done by visually inspecting any signs of wear due to the sun or other environmental factors that the ARSS may encounter. In addition to the regular visual inspections of the exterior of the robot, inspecting all of the bearings are properly greased so that there is no added friction is another. This added friction will cause the electric motors to have to overcome larger forces and thus decrease their life. The various sensors must be cleaned once a week in order for the robot to function at maximum level. After five or more years, the owner of the ARSS must verify that the drive motors are still functioning as well as verifying that any and all electrical wires are not frayed. In addition to checking for any damage to the exterior of the robot, a weather proof spray should be applied in order to ensure that any moisture will be prevented from entering the robot.

The main causes of wear and tear on the robot will be external forces and weather. The robot is equipped to move around various terrains with minimal damage to the body and electrical motors of the robot. Depending on where the user is the robot will be exposed to varying ambient temperatures as well as terrain. In extreme climates such as heavy rain, snow, or extreme heat the device should not be left outside. Such weather can affect the electrical components of the system and decrease its functionality.

8.5 Environmental Impact and Sustainability

One of the main motivations for a consumer to purchase the ARSS is to help the environment. The ARSS is designed to conserve and use less water than your average commercial sprinkler system. It also is electrically driven which is cleaner for the environment versus a petroleum driven product. Another advantage to using the ARSS is that the consumer does not need to damage their property as if they were installing a conventional sprinkler system that involves plumbing installation.

The robot is powered by a lithium ion battery which can be fully recycled at any recycling plant. The only issue with these types of batteries is the amount of money it takes to recycle them. This means that the company designing the product is responsible for the cost of recycling the lithium ion batteries. Economically, disposing of lithium batteries is the correct thing to do and should not impact the initial purchase of the product.

The majority of the robot is built out of ABS plastic which helps maintain the systems light weight and is a material that is readily available. The issue with ABS is when it comes to recycling it so that it is not harmful to humans or the planet. ABS is stable under normal conditions, however, at higher temperatures it can decompose into harmful airborne carcinogens. Exposure to these ultrafine particulates have been linked with adverse health effects. This however is an issue that will be addressed by the recycling company and will not be any cause of concern for the end user.

8.6 Economic Impact

As with any consumer product, one of the first questions always asked is how much the product costs. This is the initial idea that sparked the motivation for the design of the ARSS, to help the consumer save money. The ARSS allows the average home owner avoid the overhead cost that is involved with installing a conventional sprinkler system. In order to properly install a conventional sprinkler system, one needs to hire a contractor, have the contractor come with heavy machinery to dig trenches in the ground in order to install the water pipes. The ARSS only requires the installation of the hose reel and the charging base. One these are installed all that is left is for the hose to be attached to the water main. The cost for maintaining the ARSS is also substantially cheaper than a conventional sprinkler system. With a conventional sprinkler system, if any issues arise then a specialist must diagnose the problem and almost always involves digging into the ground in order to fix the problem. These repairs can be as short as a few hours, but they also can stretch on for days depending on the size of the system as well as the severity of the issue. The price to fix these issues also can cost a substantial amount of money ranging from the simple replacement of a sprinkler head to the main motor being burnt out. On the other hand, the ARSS can be taken to a repair shop if a problem should arise. The repairs to the ARSS are far more cost efficient and are significantly less time consuming than fixing a conventional sprinkler system. Another added benefit of using the ARSS is that it uses less water, which will in turn save the customer money.

Conventional sprinkler systems use a large amount of water and due malfunctions waste water due to inaccurate positioning or system breakdowns. Many sprinklers get jammed due to the terrain and do not allow the water to spread throughout the area. This causes a puddle to form surrounding the sprinkler head which can cause soil erosion. This also weakens the sprinkler

support as it main form of support is the compact dirt surrounding it. To have to fix these issues is a constant loss of money, and it is all due to the system not performing its designed purpose. With the ARSS system, the robot is equipped to move about the terrain and distribute water evenly throughout the area without being affected by the terrain. Due to the large area between the sprinkler and the ground, the sprinkler has minimal chance of being affected by the terrain and becoming clogged or damaged. With this design the ARSS also uses less water than traditional sprinkler systems by having a wider radius of effect. The system is designed to go out and water an area and then return to its base once it is has been covered rather than a traditional sprinkler system which relies on a timer which can be inaccurate and cause over watering. Due to the ARSS overall being far more efficient, more resilient to breakdowns, and overall less power consumption causes it to be a far more economical choice than a traditional sprinkler system.

9. Design Experience

9.1 Overview

The Autonomous Robotic Sprinkler System was a unique and interesting design. Due to its uniqueness, there were very few already established products and ideas to reference while designing the robot itself. Throughout this chapter, the steps and thought processes used in the design of the robot will be discussed. The standards used in the project will be listed and how they were incorporated. How this product will affect the consumer market economically and globally is discussed. The impact that the product will have on and for its end users is also discussed. Finally the moral and ethical responsibilities as well as the learning involved during the design process are explained and justified.

9.2 Standards Used in the Project

Due to the fact that the Autonomous Robotic Sprinkler System will be used by consumers instead of in a factory or commercial setting Occupational Safety and Health Administration (OSHA) Standard Number 1910.211 and ISO 13482:2014 standards were followed during the design process. These two standards set the requirements and procedures that must be in place for the safe operation of robots by end users. Also the IEEE safety standards that have been set for the safety of electronic systems. Standards such as 802.11 which is the standard which governs the compliance of wireless transmission devices that they do not interfere with nearby systems to create a safety hazard. These standards also state that in the event of a safety hazard a failsafe must be implemented in order to prevent and minimize damage as much as possible.

An example of the ISO 13482:2014 would be ensuring that the robot is safe to approach or handle while the system is currently running. To adhere to this standard, the robot can be turned off at any time from the water source which will make the robot approachable. An example of the OSHA 1910.211 would again be the ultra-sonic sensor to detect humans and pets, but also the built in shut off mechanism within the iRobot. The shutoff mechanism is triggered when robot's wheels leave the ground or are able to lift high enough from their compressed position within the chassis. If this does occur the entire robot will shut down and cease all functions. This is an example of an IEEE failsafe system.

9.3 Impact of Design in a Global and Societal Context

Water preservation, consumption, and waste are the three main factors that are a global concern. The main focus of this project is to aid in the reduction of water waste that occurs during conventional watering methods. This water waste reduction will be a result of the adaptability of the Autonomous Robotic Sprinkler System. Unlike traditional sprinkler systems the ARSS adapts to its surroundings. The ARSS adapts by using it's on board sensors, its ability to adjust to various sized watering areas, its ability to reduce or enhance the water flow through a controllable flow valve, and finally it actively detects and avoids obstructions in its watering path. These features will allow the ARSS to be used and adapted to any environment; whether it be a residential lawn, a small garden in a developing country, or even for temporary use in locations where a permanent system is impractical or not necessary.

The ARSS is not just a global product because of its adaptability, but also because of its price. The two main focuses of the ARSS from the beginning of is design was to be an economical and water conserving product. The current prototype for the ARSS falls just under $500. This price is only a quarter of what a traditional sprinkler system would cost just to install. The average conventional sprinkler system costs $2,450 to install [16]. This price point meets the goal of having an economic sprinkler system which ensures that it will be available globally to all who need it and not just those who can afford it. Once the ARSS's design has been streamlined for manufacturing the price should decrease even further. Another global and consumer friendly feature of this product is that it requires no professional help to set up or install.

The ARSS is available and will be usable in any country due to its ability to be useful in so many unique environments. Not only will the ARSS come with an instruction manual on how

to operate it, but it will also come with a short do it yourself guide that will allow users to modify the system to their specific needs. As mentioned previously manuals will be translated into and printed in the languages of the market in which it is being sold. Also all units will be outfitted with the proper electrical components and transformers so that they will be able to be used on whatever type of electrical grid that is available in the target market in which it is sold.

9.4 Professional and Ethical Responsibilities

The ARSS was designed first and foremost to be a consumer friendly, economical, and safe product. In order to achieve a user friendly product the goal was to make the setup of the robot as simple as possible. Set up of the robot will require nothing more than the initial installation of the robot's dock, hooking up the water source, and finally inputting the size of the lawn and the intervals at which the user wants their lawn to be watered.

The goal to keep the ARSS economical was achieved through various methods. The first was to use a readily available base robotic system that had the desired functions already built in. This was the Roomba Create 2 platform. The next step was to design attachments and enhancements for the robot that would make it safe and achieve the overall goals. The necessary parts were 3D printed to keep costs low, utilizing plastics when necessary and keeping high cost materials to a minimum. All other components added to the system were added as necessary and were purchased to fulfill the specifications required only in order to reduce excess power consumption and waste.

All parts used and methods of manufacturing used in this product once it reaches full production level would be ethically produced and sourced. All materials present would be non-toxic and would be made of the highest standards possible so as to ensure that there would be no contamination during the watering process. The parts used would be made out of sustainable materials as well as manufactured to high quality standards as this is a system that is meant to be used in everyday life. No parts would be made with a specific life cycle in mind but would all be made with infinite life cycles in mind so as to provide a long standing and reliable product. Another area of ethical responsibility to the end user would be to ensure that all specifications would be met and adhered to. None of the printed numbers would be based off of

premanufactured or theoretical values, instead the specifications would be based upon actual test results in real world environments.

9.5 Life-Long Learning Experience

The learning process during this design was one that helped fully realize the need for life-long learning and the need for proper planning. New technologies are always constantly emerging and the need to understand these technologies is even more important. Staying on top of the latest trends and technologies or personal and professional knowledge helps to make you a smarter and more effective engineer. These new technologies could be integrated into ongoing projects that could be significantly bettered by the new technology. Even existing projects that have been completed still need to be maintained properly and updated accordingly can benefit from a well read and updated engineer.

Life-long learning however is not just about staying on top of the latest engineering knowledge however. Many things are necessary to be a successful engineer; whether it is intrapersonal skills, public speaking, or being a prompt person. These life skills can't be learned during four short years of University, in fact most of them aren't taught at all. Most of them are cultivated over long periods of time through self-discipline and learning. In the end it is about ensuring that as an engineer one maintains a professional, moral, and ethical code in everything that they say, think and do.

9.6 Discussion

Throughout this project, a number of skills were gained, lessons learned, and goals achieved. One of the lessons learned is that no matter how well plans are laid, something will go wrong. Whether it be the availability of team members, parts failing, or something not fitting once all the parts are assembled. Meetings are a crucial and vital part of the design process. Not only for communication, but for smooth and accurate execution of the plans laid during the meetings.

Working in a group is a constant cycle of new ideas, changing plans, and sometimes heated arguments, but overall the work that can be accomplished is far greater than what one would be able to accomplish alone. Thinking about a problem three different ways and discussing it almost always ensures that the best solution will be implemented. Things don't get done in one day is a phrase that is often heard but not understood until a project of this magnitude has been attempted. This project was not done in one day, but through careful planning, good communication, and a willingness to accept new ideas and changes as the design developed, the Autonomous Robotic Sprinkler System was brought to life.

10. Conclusion

10.1 Conclusion and Discussion

In conclusion, as a team, an autonomous robot capable of watering medium sized areas has been designed and tested. Due to time constraints, not every feature was able to be built in as desired. Even if everything wasn't included, this is normal in the design process anywhere in the design industry. Regardless, the team feels that it has accomplished what it set out to do. There is always time for future work and perhaps even pitching the idea as a product to a robotics company who may add even more value to what we consider a work in progress. Throughout this experience, much has been learned about design and engineering. Team work is crucial to creating any type of project or product. Even more crucial when working with something as complicated as robots and programming.

Testing has been conducted for the robot and while not all results were not as ideal as the team had hoped them to be, there is a lot to be learned from this project which includes improvements, better experiment design and a more solid understanding of the programming that made this project feasible. This chapter will close out by discussing the evaluation of integrated global design aspects, evaluation of intangible experiences, patent/copyright claim, commercialization, and future work that could be done in order to improve the project.

10.2 Evaluation of Integrated Global Design Aspects

Looking back at this experience, several of the integrated design aspects have been included such as support for world wise standards in electricity distribution. The project is rated to work with 50/60Hz and 120/240 V standards with the correct adapters. The voltage regulators found on the Arduino microcontroller also makes it possible to deal with varying voltage standards as well.

Minimal text associated with the project makes it much easier to use visual aids rather than instructions for first time set up. Visual aids and stickers create a globally friendly product to anyone no matter what language or dialect they may speak. If time had permitted, an instruction manual in more than one language would have been developed to allow the product to be more approachable to those who prefer text rather than visual aids.

One important subject worth discussing is the use of both SI and English units to allow the data from experimentation to be easily shared without any speed bumps. With a system as complicated as the robot, it would definitely be very important to think about global design from this perspective. That is why, all data in this report is included in both units for ease of reading and analysis.

Some locations around the world do not have regular access to water so this product needed to be able to save water or at least quantify how much water is being used so as to not go over ordnance set by local governments. If there are no issues of this sort, it is still very useful to know how much water is being consumed in the watering of any area. This could help consumers be wary of how much they may be impacting the environment.

Starting out, this project was always intended to be a medium sized area watering robot that was cost effective. Some countries around the world have a much weaker currency compared to the dollar or euro. This creates an issue where products that are more or less affordable in the United States may be impractical to buy in other countries. Creating a product that will be fairly priced is ethically responsible. As a result of this, it is expected that some sales may generate negative revenue, but at the same time, knowledge and popularity of the product will rise and maybe positive public relations worldwide will ultimately lead to more sales/revenue in desired countries.

As of the finishing of this project, the team has spent a combined $500 in order to build the prototype. A rule of thumb for mass manufacturing is that material costs are half of what they cost wholesale. Creating deals with suppliers is integral to developing a successful product. Even more so when these materials are sourced internationally in order to help the global market.

10.3 Evaluation of Intangible Experiences

When the team first set out to design this project and create something that doesn't really exist out in the market, it was assumed that most of the design process would be straight forward. After a few weeks into the project, this was clearly not the case. When looking down from a very general point of view onto a project, one loses sight of the very important and miniscule things. Creating meetings and making the time to work on the project was very difficult as there were other obligations that team members had to attend to.

Going back to the topic of small things, looking at the ARSS system from a top down approach, an autonomous robot which is capable of watering a lawn is much easier to say then to actually get a working prototype. There were issues with part creation such as size and fit which cannot be accounted for until the actual parts are in hand. Other issues that came up were the difficulty and troubleshooting in getting the robot and Arduino to communicate with each other in order to send and receive commands. Ultimately, several things were learned during the planning and construction of the ARSS. One experience that was definitely not foreseen was the need to learn how to solder. Several parts that were shipped which were used on the robot needed to be soldered or modified in order to function as intended. For example, the LCD screen attached to the ARSS required over 40 solder joints in order to operate. Unfortunately, it did not work until all the joints were redone due to errors.

Part creation, especially the plastic structure which holds and attaches the sprinkler head to the robot were difficult to create because of obstacles faced during the 3D printing process which were out of the control of team members. Countless hours of trial and error and troubleshooting finally ended in the successful part creation which can be observed on the prototype.

Aside from the hardware point of view, team members had to support each other and sometimes fill in the shoes of others in order to move forward or pass through bottlenecks. These types of occurrences cannot be accounted for until the moment the project approaches crucial checkpoints and bottlenecks.

In writing this report, the amount of time it took to get it to be presentable and professional also was a surprise and even then, improvements can still be made as with every publication that is available in the literature. One assumes that the chapters can be written and the content required would be easy to come across and present. The two largest factors that the project consisted of were last minute prototype adjustments like programming/connections and the writing of this report.

Viewing an intangible experience with a negative connotation would be the incorrect thing to do. One learns the most when one experiences mistakes or does not foresee critical elements required for a process paving the way to documentation which will help future generations that may be facing the same challenges. The experiences gained during the formulation of this project have taught things such as responsibility, creativity, and time management that could be applied to the work place and in the pursuit of lifelong learning.

10.4 Commercialization Prospects of the Product

To prepare the Autonomous Robotic Sprinkler System for mass production, it will have to be streamlined, updated, and specific materials will have to be chosen. One option to accomplish these goals would be to take it to a company such as G3 Engineering Design. A company that take's products and ideas through each phase of the design and commercialization process; feasibility, design, prototypes, and manufacturing. This would be an effective method to obtain a fully functioning product while obtaining the added benefit of input from actual engineers in the industry.

A cheaper alternative to an engineering services company would be to pitch the ARSS to businesses that already make similar products. This type of approach would have a unique set of benefits that would come along with it. This would not only allow for input from industry engineers in terms of design, but due to their sponsorship, the company itself would be invested in the overall success of the product. This would lead to partnership not only in terms of the design of the product, but in the areas of marketing and sales as well.

To market the ARSS the first thing to consider would be the target audience. Is the ARSS going to be marketed solely to home owners, or farmers and small businesses as well? The ideal market of course would be the small home owner, business owner, or even home garden enthusiast that needs a sprinkler system but cannot afford to install a conventional one. The next question is where does one sell this type of product? Seeing as it does not have too many competitors as has been shown in previous sections the market is rather wide open.

The initial idea would be to market it in the home and garden section of large commercial chains such as Wal-Mart, Target, Lowes, and Home Depot. Other potential markets such as

online can be covered by large online retailers such as Amazon. This will not only enable the product to be widely marketed, but due to the online sales will be available to anyone who wishes to purchase it. This would not only achieve a widespread distribution of the ARSS, but would also accomplish the goal of the ARSS becoming a global product.

10.5 Future Work

The Autonomous Robotic Sprinkler System while a functioning prototype still has quite a ways to go before it is ready for store shelves. Some of the potential ideas for the ARSS include adding a solar panel to the system in order to take the system off the grid, reduce energy costs to the owner, and ultimately utilize a clean energy source. This would not only be beneficial to the owner themselves, but allow the product to be even more widely available in other markets such as developing countries.

A second suggestion would be a few ideas packed into one, specifically reduce the overall size and footprint of the ARSS itself. Due to the fact that the ARSS is currently built upon an iRobot Create 2 programmable and modified kit style robot. However, a chassis could be designed specifically for the purposes of the ARSS. A system containing stronger motors for rougher terrain and larger wheels capable of traversing various terrains without damaging its surroundings. These would have to be developed and designed with a water tight system in mind. Marine grade electronics would be utilized, non-rusting and sun resistant materials such as aluminum will be used for the chassis and sprinkler supports. Overall by minimizing the variety of materials used, having all of the electronics and sensors centralized on a single circuit board, and having a custom chassis and sprinkler head the ARSS will become a compact and efficient system.

One part of the ARSS system that never had time to be developed was the reel system which would help with controlling the hose. The concept is set in place, but needs to be manufactures. ARSS on its own is incapable of functioning as designed without this reel so getting it finished would be a big step in the project.

The user interface for the ARSS currently asks for the user's lawn size and schedule at which they wish their lawn to be watered. It then proceeds to draw a watering path through this size area and using its sensors avoids obstacles within its path. In the future, this user interface would become a much more user friendly graphical user interface capable of custom watering patterns for various flora and fauna. For instance one portion of a lawn may be grass but another portion may be more delicate such as a flower bed or home garden. These types of areas usually require less volume and pressure when being watered. By having a GUI capable of custom water flow patterns the ARSS will become and even more enticing and useful product.

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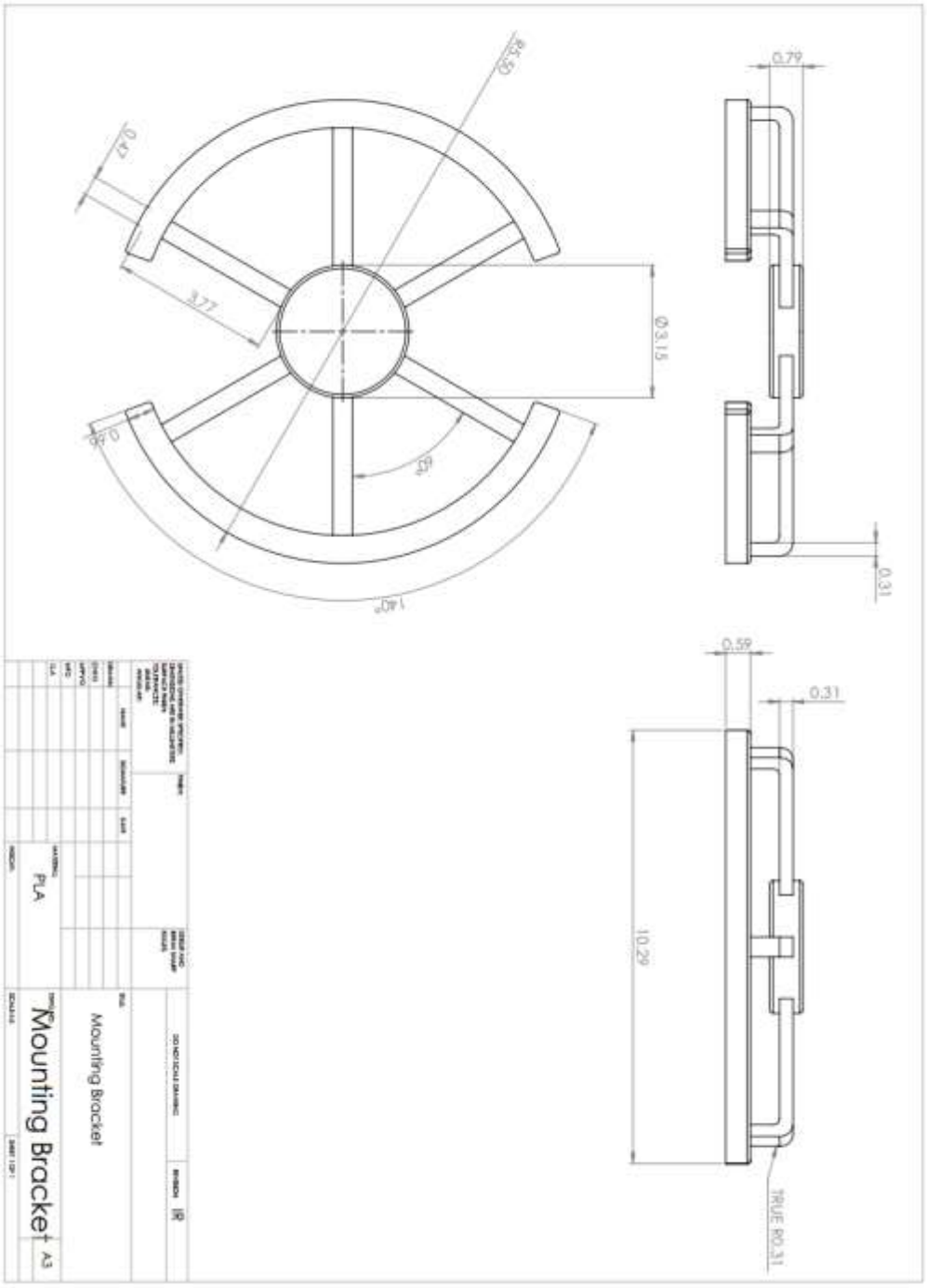
Appendix

A.1 Technical Drawings



A.2 User Manuals

Tools / Materials you will need.

1x - Corded Drill

1x - Hammer

1x - No.2 Phillips Head Screwdriver

1x - Level

1x - 1/8” Cement Drill bit

(All parts below are included in the ARSS installation kit)

1x - 2’x2’ Charging Platform

1x – Charging Dock

4x - Plastic Wall Anchors

4x - Aluminum Stakes

4x - 1/8” Stainless Steel Screws

4x - Stainless Steel Bolts

1x - 50’ Clearflow Hose

Step 1: Installing the hose reel and charging station.

To install the hose reel, choose a location directly that is near an external main water source available from your home. Next four holes will need to be drilled in order to mount the

hose reel system. Once the holes are drilled insert the Plastic Wall Anchors using the hammer to tap them into the holes. Mount the hose reel using the four 1/8" Stainless Steel Screws found in the installation kit. To ensure maximum performance of the hose reel be sure to mount the system at an even level as tilting or skewed mounting will cause the reel's swivel to operate improperly. This can be accomplished by properly marking the holes to be drilled by holding the mounting bracket to the wall and using a level.

Step 2: Installing the charging dock.

The charging dock will be installed directly below the hose reel. First take the 2'x2' charging platform and secure it in place using the four aluminum stakes provided in your installation kit. Each stake will be place in its corresponding hole located at each corner of the platform. These can be driven into the ground using your foot, however if increased resistance is found the hammer may be used as well. Once the platform has been secured it is time to install the charging dock. Using the four stainless steel bolts found in your installation kit you will secure the charging dock to its platform. There are four screw holes marked on your platform. Align the four holes of the charging dock with the screw holes on the platform and use the No.2 Phillips Head Screwdriver to install the bolts.

Step 3: Installing the hose.

Once the hose reel is mounted securely on the wall it is time to install the hose itself. The short 2' supply hose that comes out of the center of the hose reel should be attached at the main water source. The 50' Clearflow hose that came in your installation kit will be attached at the center of the hose reel itself. Once connected manually reel the hose onto the reel, leaving 4' excess at the end. This 4' lead will now be connected to the sprinkler on the top of your ARSS.

Ensure that all connections are properly tightened so as to avoid any leakages which can caused decreased performance when watering.

Step 4: Setting your desired watering radius and sprinkler setting.

At the base of the sprinkler on the ARSS is a ball valve which is used to control the desired radius of your sprinkler. One quarter, One half, Three Quarters, and Full open are the options, choose what is best for your size lawn or garden. Once the valve is set, rotate the top of the sprinkler to choose your spray pattern.

Step 5: Charge the ARSS.

Plug your ARSS into its charging dock, look for the LED indicator to turn on, and leave it to charge over-night.

Step 6: Programming your ARSS.

Don’t worry you won’t have to actually program your ARSS, we have done this for you. All you will have to do is use the LED panel located on the side of your ARSS and input: your chosen valve setting, lawn size, and at what time of day you want your lawn to be watered.

Step 7: You are done! Congratulations on installing your ARSS. Enjoy your new water saving environmental friendly sprinkler system.

Guide d'installation espagnole

Herramientas / Materiales que se necesitan.

1x - Taladro con cable

1x - Hammer

1x - No.2 Phillips Destornillador

1x - Nivel

1x - 1/8 "Cemento Drillbit

(Todas las partes inferiores están incluidas en el kit de instalación ARSS)

1x - 2'x2 'de carga Plataforma

1x - Base de carga

4x - plástico Anclajes de pared

4x - estacas de aluminio

4x - 1/8 "Tornillos de acero inoxidable

4x - Acero inoxidable Tornillos

1x - 50 'Clearflow Manguera

Paso 1: Instalación del carrete de la manguera y la estación de carga.

Para instalar el carrete de manguera, elija una ubicación directamente que está cerca de una fuente principal de agua externa disponible de su casa. Tendrán que ser perforado con el fin de

montar el sistema de carrete de manguera próximos cuatro agujeros. Una vez que los agujeros son perforados inserción del Muro de plástico anclas utilizando el martillo para golpear en los agujeros. Monte el carrete de manguera con los cuatro tornillos de 1/8 "de acero inoxidable que se encuentran en el kit de instalación. Para garantizar el máximo rendimiento del carrete de manguera, asegúrese de montar el sistema en un nivel aún como la inclinación o montaje sesgada causarán giratoria del carrete para operar de manera incorrecta. Esto se puede lograr mediante el marcado adecuadamente los agujeros para ser perforados sosteniendo el soporte de montaje a la pared y el uso de un nivel.

Paso 2: Instalación de la base de carga.

Se instalará el muelle de carga directamente debajo del carrete de manguera. Lo primero a tener la plataforma de 2'x2 'de carga y fijarlo en su lugar con las cuatro estacas de aluminio que aparecen en el kit de instalación. Cada juego será lugar en su correspondiente orificio situado en cada esquina de la plataforma. Estos pueden ser accionados en el suelo con el pie, sin embargo si no se encuentra una mayor resistencia que el martillo se puede utilizar también. Una vez que la plataforma ha sido asegurado es el momento de instalar la base de carga. Usando los cuatro pernos de acero inoxidable que se encuentran en su kit de instalación se le asegure la base de carga para su plataforma. Hay cuatro orificios de los tornillos marcados en su plataforma. Alinee los cuatro orificios de la base de carga con los orificios para tornillos de la plataforma y utilizar el N º 2 Destornillador Phillips para instalar los pernos.

Paso 3: Instalación de la manguera.

Una vez que el carrete de la manguera esté bien montada en la pared es el momento de instalar la misma manguera. El corto 2 'manguera de suministro que sale del centro del carrete de la

manguera debe estar unido a la fuente principal de agua. El 'manguera de 50 Clearflow que viene en el kit de instalación se adjuntará en el centro del carrete de manguera de sí mismo. Una vez conectado el carrete manualmente la manguera en el carrete, dejando 4 'exceso al final. Plomo Este 4 'ahora se conecta a la aspersión en la parte superior de su ARSS. Asegúrese de que todas las conexiones estén bien apretados para evitar cualquier fuga que puede causó pérdida de rendimiento al riego.

Paso 4: Ajuste de la configuración de radio de riego y aspersión deseada.

En la base del aspersor en la ARSS es una válvula de bola que se utiliza para controlar el radio deseado de su aspersor. Una cuarta parte, la mitad, tres cuartos, y abierto completo son las opciones, elegir lo que es mejor para su césped tamaño o jardín. Una vez que se establece la válvula, gire la parte superior del aspersor de elegir su modelo de pulverización.

Paso 5: Cargue la ARSS.

Conecte su ARSS a su base de carga, busque el indicador LED se enciende, y dejar que se cargue durante la noche.

Paso 6: Programación de su ARSS.

No se preocupe usted no tendrá que programar realmente su ARSS, hemos hecho esto para usted. Todo lo que tienes que hacer es utilizar el panel LED situado en la parte lateral de su ARSS y de entrada: el ajuste de la válvula elegida, el tamaño del césped, y en qué momento del día en que desea que su césped para regar.

Paso 7: Usted está hecho! Felicitaciones por la instalación de su ARSS. Disfrute de su nuevo sistema de rociadores respetuoso del medio ambiente ahorro de agua.

Guide d'installation Français

Outils / Matériaux dont vous aurez besoin.

1x - perceuse à fil

1x - Marteau

1x - No.2 tournevis cruciforme

1x - Niveau

1x - 1/8 "Drillbit Cement

(Toutes les pièces ci-dessous sont inclus dans le kit d'installation de ARSS)

1x - 2'x2 'Plate-forme de chargement

1x - Charging Dock

4x - plastique Chevilles murales

4x - Aluminium Stakes

4x - 1/8 "vis en acier inoxydable

4x - Acier inoxydable Boulons

1x - 50 'Tuyau Clearflow

Étape 1: Installation du dévidoir et de la station de charge.

Pour installer le dévidoir, choisissez un emplacement directement qui est à proximité d'une source d'eau principale externe disponible à partir de votre maison. Suivant quatre trous devront

être percés afin de monter le système de dévidoir de tuyau. Une fois que les trous sont percés Insérez les ancrages du mur de plastique en utilisant le marteau pour les puiser dans les trous. Monter l'enrouleur à l'aide des quatre vis 1/8 "d'acier inoxydable trouvés dans le kit d'installation. Pour assurer une performance maximale du dévidoir être sûr de monter le système à un même niveau que l'inclinaison ou montage biaisé vont provoquer la rotule de la bobine ne pas fonctionner correctement. Ceci peut être réalisé par marquage correctement les trous à percer, tenue par le support de fixation à la paroi et en utilisant un niveau.

Étape 2: Installation de la station de charge.

Le quai de chargement sera installé directement en dessous de l'enrouleur. D'abord prendre le 2'x2 'charge la plate-forme et le fixer en place à l'aide des quatre piquets en aluminium fournies dans votre kit d'installation. Chaque jeu sera place dans son trou correspondant situé à chaque coin de la plate-forme. Ceux-ci peuvent être enfoncés dans le sol avec le pied, si la résistance accrue se trouve le marteau peut être utilisé aussi bien. Une fois la plate-forme a été obtenu, il est temps d'installer la station de charge. En utilisant les quatre boulons en acier inoxydable trouvés dans votre kit d'installation vous sécuriser la station de charge à sa plate-forme. Il ya quatre trous de vis marqués sur votre plate-forme. Alignez les quatre trous de la station de charge avec les trous de vis sur la plate-forme et utiliser le No.2 tournevis cruciforme pour installer les boulons.

Étape 3: Installation du tuyau.

Une fois que le dévidoir de tuyau flexible est monté fixe sur le mur, il est temps d'installer le tuyau lui-même. Le court 2 'tuyau d'alimentation qui sort du centre de la bobine de tuyau doit être attaché à la source d'eau principale. Le 50 'Clearflow tuyau qui est venu dans votre kit d'installation sera attaché au centre de l'enrouleur de tuyau lui-même. Une fois connecté Bobine

manuellement le tuyau sur la bobine, laissant 4 'excès à la fin. Ce plomb 4 'va maintenant être connecté à l'arroseur sur le dessus de votre ARSS. Assurez-vous que toutes les connexions sont bien serrées afin d'éviter les fuites qui peut causé une baisse des performances lors de l'arrosage.

Étape 4: Configuration de votre rayon d'arrosage et d'arrosage réglage désiré.

A la base de l'arroseur sur le ARSS est un clapet à bille qui est utilisé pour contrôler le rayon souhaité de votre arroseur. Un quart, la moitié, les trois quarts, et ouvert complet sont les options, choisir ce qui est le mieux pour votre pelouse de la taille ou le jardin. Une fois que la vanne est réglée, faites pivoter le haut de l'arroseur pour choisir votre modèle de pulvérisation.

Étape 5: Chargez la ARSS.

Branchez votre ARSS dans sa station de charge, regarder si le voyant LED pour allumer, et laisser charger pendant la nuit.

Étape 6: Programmer votre ARSS.

Ne vous inquiétez pas, vous ne devrez pas réellement programmer votre ARSS, nous l'avons fait pour vous. Tout ce que vous aurez à faire est d'utiliser le panneau LED située sur le côté de votre ARSS et entrée: votre réglage de la vanne choisie, la taille de la pelouse, et à quel moment de la journée que vous voulez que votre pelouse pour être arrosé.

Étape 7: Vous avez terminé! Félicitations pour l'installation de votre ARSS. Profitez de votre nouveau système de gicleurs respectueux de l'environnement d'économie d'eau.

A.3 Sample Code

This is a sample code to communicate with ARSS and send commands for testing.

```
#include <SoftwareSerial.h>


int rxPin = 3;

int txPin = 4;

int ledPin = 13;


SoftwareSerial Roomba(rxPin,txPin);


#define bumpright (sensorbytes[0] & 0x01)

#define bumpleft  (sensorbytes[0] & 0x02)


void setup() {

 pinMode(ledPin, OUTPUT);   // sets the pins as output

 Serial.begin(115200);

 Roomba.begin(19200);
```

```
delay(500);




digitalWrite(ledPin, HIGH); // say we're alive

Serial.println ("Sending start command...");

delay (1000);

 // set up ROI to receive commands

Roomba.write(128);  // START

delay(150);



Serial.println ("Sending BRC packet...");

Roomba.write(129);

Roomba.write(7);

delay(300);



Serial.println ("Sending Full Mode command...");

delay (1000);
```

```
Roomba.write(132);  // CONTROL

delay(200);

digitalWrite(ledPin, LOW);  // say we've finished setup

Serial.println ("Ready to go!");

delay (1000);




/*for(int x = 31; x < 100; x++)

{

 Serial.print ("Sending Song command... ");

 Serial.print(x);

 Serial.println("");

Roomba.write(140);

Roomba.write(1);

Roomba.write(1);

Roomba.write(x);

Roomba.write(32);
```

```
 Roomba.write(141);
 Roomba.write(1);
 delay(515);
 }
 */
 //Roomba.write(173);
}

void loop() {
 digitalWrite(ledPin, HIGH); // say we're starting loop
 Serial.println ("Go Forward");
 goForward();
 delay (500);
 Serial.println ("Halt!");
 halt();
 Serial.println ("Go Backwards");
 delay (500);
```

```
 goBackward();
 delay (500);
 Serial.println ("Halt!");
 halt();
 while(1) { } // Stop program
}

void goForward() {
 Roomba.write(137);   // DRIVE
 Roomba.write((byte)0x00);   // 0x00c8 == 200
 Roomba.write(0xc8);
 Roomba.write(0x80);
 Roomba.write((byte)0x00);
}
void goBackward() {
 Roomba.write(137);   // DRIVE
 Roomba.write(0xff);   // 0xff38 == -200
```

```
 Roomba.write(0x38);

 Roomba.write(0x80);

 Roomba.write((byte)0x00);

}



void halt(){

byte j = 0x00;

Roomba.write(137);

Roomba.write(j);

Roomba.write(j);

Roomba.write(j);

Roomba.write(j);

}
```